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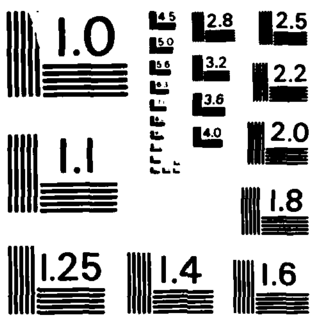

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TECHNOLOGY MODERNIZATION: A DECISION SUPPORT SYSTEM INCORPORATING EXTENSIONS OF DATA ENVELOPMENT ANALYSIS FOR PRIORITIZATION OF CONTRACTS

THESIS

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THESIS

Presented to the Faculty of the School of Systems and Logistics
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Logistics Management

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Gregory F. Padula

and

Gerald W. Pellett

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Abstract

Technology Modernization (Tech Mod) is a DoD effort to incenitvize U.S. industry to modernize their facilities and procedures. For DoD personnel to effectively manage the Tech Mod programs, they must not only understand the Tech Mod processes, but also the factors that control and influence the process. This thesis examines the environment that Tech Mod operates in, studies three Tech Mod decision processes, develops a normative decision process that can serve as a basis for a decision support system (DSS), and finally, it demonstrates how the normative model developed can be used in a DSS. The study of the Tech Mod environment coupled with the Tech Mod case studies were used to develop the normative model. In exploring ways to expand one of the modules in the flow diagram, the researchers developed a prioritization technique using as a basis the linear programming technique called Data Envelopment Analysis. The method developed ranks multiple input/output contracts using technical and allocation efficiencies as a basis. The method further allows the decision maker to analyze the prioritization scheme from several perspectives, thus giving him a better understanding of the problem (inputs/outputs). The method may have generic application for profit and non-profit organizations alike. Further research in this area should prove fruitful.

TECHNOLOGY MODERNIZATION: A DECISION SUPPORT SYSTEM INCORPORATING EXTENSIONS OF DATA ENVELOPMENT ANALYSIS FOR PRIORITIZATION OF CONTRACTS

I. Introduction

In 1978, during the course of the lightweight fighter acquisition, the F-16 Systems Program Office (SPO) instituted a program called Technology Modernization (Tech Mod). The program, as originally conceived, was intended to induce the prime systems contractor (General Dynamics) into making substantial capital investments to modernize the production facilities at Air Force Plant No. 4, Fort Worth, Texas. The program was implemented to improve F-16 quality and reduce system lead time and cost. A further benefit of Tech Mod was its perceived impact on the aerospace industrial base, at a time when productivity within aerospace industries was becoming a cause for much concern. The Air Force acquisition community adopted the program as a vehicle to provide incentives for contractor capital investments.

Tech Mod attempts to integrate current manufacturing technologies, private sector capital investments, and contractual incentives in a large-scale productivity

enhancement plan. In essence, the program is an alliance or partnership between the Air Force and selected contractors with the principal objective of improving the health of the aerospace industry. This thesis attempts to examine the economic environment which created the need for Tech Mod, and to describe the decision process through which contractors (and individual projects at contractor facilities) are selected to participate in Tech Mod. Additionally, a decision support system (DSS) is proposed herein, which would aid Air Force managers involved in the Tech Mod selection process. The proposed DSS explores the possibility of using the linear programming technique known as Data Envelopment Analysis (DEA), with some extensions, to prioritize Tech Mods.

Thesis Overview

This thesis is written for individuals with varied backgrounds and degrees of involvement in the Tech Mod program. Chapter 1 explains the Tech Mod problems that the thesis will address, and provides a brief background on the Tech Mod concept. Chapter 2 incorporates much more detail on the environment that spawned Tech Mod, while Chapter 3 explains the methodological approach followed in the development of this research effort. In Chapter 4, decision processes of managers involved in Tech Mod selection are examined via specific case analyses, and Chapter 5

synthesizes these descriptive models into a normative one which incorporates a contemporary DSS. Chapter 6 expands the prioritization section of the normative model and explores the feasibility of using a linear programming technique called Data Envelopment Analysis (with extensions) to rank proposed Tech Mod programs (and even individual projects within programs). Finally, Chapter 7 will report the findings, recommendations and conclusions of this research effort.

Chapter Overview

This chapter provides a macro view of Tech Mod to familiarize the reader with the economic conditions that led to creation and expansion of the program. Included are a statement of the specific problem being treated, as well as a brief history of industrial problems that require resolution, leading to a statement of the Tech Mod concept and the policy which makes Tech Mod a reality. Also presented are a statement of the scope of the study, and research objectives and questions.

Specific Problem

The Tech Mod concept is relatively new (post-1978), but its demonstrated potential is substantial. Combined program costs and benefits--that is, government and industry modernization investments plus generated savings--are

expected to total in the billions of dollars. The proper investment of Tech Mod funds directly affects resultant benefits (accrued savings, improved industries, etc.); therefore, an Air Force manager or decision maker responsible for selecting firms to participate in Tech Mod (or for selecting individual modernization projects to pursue with a contractor under the purview of a Tech Mod contract) will want to choose programs (or projects) that will generate the greatest benefits for both parties.

In order for decision makers to produce optimal decisions concerning Tech Mod program or project selection, they must understand not only the selection process, but also the many factors that impact selection. These factors are an aggregation of possible selection criteria, and include both subjective and objective (qualitative and quantitative) considerations. To date, Tech Mod programs and projects have been chosen primarily on the basis of subjective evaluation of candidates. A substantial amount of quantitative data is available, though unused unless considered subjectively, and an objective evaluation of such information (criteria) could result in better selection procedures, and eventually, greater benefits.

Background

The end of World War II saw the emergence of the United States as the major industrial force in the world

largely because it was the only major industrial power whose production base had not been damaged by years of war. In truth, the United States was in a far superior position economically than it had been when the war began, and U.S. industry expanded to meet the demand of the world by absorbing many markets that had previously been served by other nations. This rapid industrial expansion led to many inefficiencies that were often overlooked because profits were sufficient. While it is always more profitable to produce any level of output at the minimum cost, the absence of competition means there are no compelling market forces which drive production costs to a minimum (38); in many cases, U.S. industry was producing at inefficient levels because of the monopoly power it commanded and its dominant position in the world market. However, as other nations began rebuilding their industrial bases, U.S. firms began losing more of the global market share, which in turn eroded their monopoly power and profits. As profits declined and then turned to losses, some U.S. companies were forced out of business. Many possible and plausible factors explain the decline of U.S. firms' competitiveness in the world market. Among them are: the principle of comparative advantage, which suggests that eventually a nation's industries will focus on those things they do best; the adjustment of exchange rates after the post-war recovery; a long-term trend of other nations recapturing their "natural"

markets following recovery; and finally, the idea that U.S. businesses had pursued the short-term profit orientation rather than developing a long-term investment strategy (38).

Regardless of which of these explanations one ascribes to, the lack of a long-term investment strategy by U.S. companies has apparently contributed to the U.S. losing ground in the now competitive world market, and more importantly, it seems to have had a deleterious effect on those firms which comprise the defense industrial base. Several government and civilian studies have indicated that our industrial base is deteriorating, and deteriorating rapidly (8; 9; 35; 58). U.S. government leaders are attempting to reverse this alarming trend toward decreased productivity in the defense sector of U.S. industry.

Current efforts to improve the productivity of our aerospace industrial base fall into two main categories, according to one government study (2). The first category is called contracting for productivity, and it is a strategy through which the government "uses traditional and innovative contracting techniques to solicit, 'incentivize' and sustain contractors in increasing productivity [2:ii]." This method makes use of such things as multi-year contracts and indemnification clauses to induce contractors to become more efficient and productive.

The second main thrust directed at improving industrial productivity of the aerospace base is the concept

known as Technology Modernization. Tech Mod was developed within the framework of the F-16 acquisition program, which involved the U.S. Air Force and General Dynamics. Production facilities used by General Dynamics to manufacture the F-16 aircraft were in dire need of modernization, but a DoD policy change in 1975 kept the Air Force from sharing in capital acquisition costs and created a dilemma for the contractor. General Dynamics' dilemma was the same one that would confront all DoD contractors--namely, that while modernization would reduce system cost and leadtime (i.e., make General Dynamics more productive), it would also reduce company profits. For example, if General Dynamics could produce F-16 aircraft at $10M a copy and their profit was 10% they would make $1M profit per aircraft. If they invested $200M in modernization and reduced aircraft cost to $5M each, their profit (at 10%) would then be $500K per aircraft. Under these circumstances, a new scheme for incentivizing contractor capital investments was needed, and Tech Mod was to be the vehicle for providing those incentives.

Tech Mod is a direct approach for expanding the industrial base, and incorporates a combination of technology, private sector capital investments, and contractual incentives in a large scale productivity enhancement plan. A Tech Mod is normally completed in three phases. In Phase I, a factory analysis is completed, which

evaluates contractor facility needs and identifies candidate technologies. During Phase II, implementation plans are drawn up and enabling technologies are developed. Phase III is the actual implementation of the Tech Mod, and includes purchase and installation of capital equipment by the contractor.

Former Aeronautical Systems Division (ASD) Commander, General Skantze directed that ASD Regulation 800-4 incorporate Tech Mod as a mandatory consideration for each major acquisition program (2:ii). Additionally, the Tech Mod concept has been expanded by ASD to target specific sectors of the aerospace base. This proliferation of Tech Mod can produce substantial benefits for the DoD and industry, provided those individuals involved in Tech Mod make appropriate decisions concerning selection of firms (and projects within firms) for Technology Modernization. This thesis focuses on the decision process through which Tech Mods are chosen; and by analyzing successfully implemented programs, attempts to develop a structured view of their processes. A further extension of the decision process is then explored in the development of a DSS which incorporates a prioritization scheme based on quantified criteria.

Scope of Research

This study is principally an examination of the decision processes of Air Force managers currently involved in Tech Mod and a synthesis of those processes into a "generic" decision structure. The generic decision process is actually a normative view of Tech Mod which proposes a DSS to facilitate overall program management. The thesis explains how the DSS would function in general terms, but the software to implement the DSS has not been developed herein.

Research Objectives and Questions

The fundamental objective of this thesis is to describe the decision making process of Air Force managers involved in Technology Modernization. The more specific objective of this research is to develop a decision support system to aid Air Force personnel, primarily those with no previous exposure to the program, in managing a Tech Mod and in making sound decisions concerning the program.

In order to accomplish these stated research objectives, existing and collected information and data was analyzed to provide insight into, and answers for, the following questions:

1. Why is there a need for the Technology Modernization program?

2. What decision process has been utilized to select previous Tech Mod programs and projects?

3. How would a DSS be structured to assist Tech Mod management, including program or project selection?

4. What technique or method can be used to prioritize Tech Mod proposals and simultaneously take into account multiple criteria?

II. The Tech Mod Environment (Literature Review)

Chapter Overview

This chapter contains the literature review portion of the thesis. Included herein are a description of the defense industrial base from an historical perspective and a look at the structure of defense industry and contractor/government incentives. The final section of this chapter focuses on literature which explains the need for Tech Mod, including a discussion on that program's potential as a solution to industrial problems, and an assessment of the two distinct approaches to Technology Modernization.

The Defense Industrial Base: Historical Perspective

In the late 1930's, as the world situation deteriorated and war in Europe seemed imminent, the majority of Americans felt secure in isolation and preferred to avoid foreign entanglements. The United States was clearly one of several major industrial powers in the world at that time, but the focus of American industry was on consumer goods and services, and not military hardware (72:208). The United States was not prepared to engage in a conflict of global proportions, and wished to remain neutral--protected by two

vast oceans (58:8). However, behind the facade of neutrality, American sympathies favored the British; and in March of 1941 Congress passed what came to be known as the Lend-Lease Act (46:39; 53:2-9). The Lend-Lease Act provided the impetus for a massive conversion to, and growth of, defense industries; in effect, the United States became the "arsenal of democracy" exhibiting unparalleled advances in productivity (10:74; 46:38; 53:2-9).

Throughout the remainder of the war, the U.S. defense industrial base continued to expand; and America's industrial might eventually overwhelmed the Axis alliance which had been formed by Germany, Italy and Japan (58:8). According to Bluestone, Jordan and Sullivan (19:27), ". . . the American industrial effort was the pivotal factor in World War II, and the aircraft industry was the cornerstone of that effort." United States industry had responded admirably, and in fact, the U.S. emerged from the war as <u>the</u> major industrial force in the world. The U.S., undamaged "by the devastation of actual combat and with a sound economy," was able to support the reconstruction of war-torn Europe and keep sufficient numbers of troops under arms to discharge "inherited" responsibilities as leader of the free world (53:2-10).

Following the war, the defense industry infrastructure remained intact, but the majority of industrial resources were reallocated to meet "consumer demand for commercial

products deferred during the war [58:8]." Limited resources were allotted to military procurement, and the specialized nature of these type acquisitions led to a government-directed defense industry comprised of a few large subsectors which could meet most needs of the U.S. armed forces (69:31; 71:27). The substantial expansion of the U.S. defense industrial base during the Second World War accounted for the healthy industrial base when the United States went to war in Korea, and industry was able to produce most of the material and hardware needed to conduct the Korean campaign. When the United States became embroiled in the conflict in Southeast Asia, the transition to a wartime footing was again accomplished with comparative ease, largely because the U.S. government controlled the pace of the buildup (58:9). Actually, it wasn't until the post-Vietnam War era that concerns about the health of U.S. defense industry were raised (35:21; 58:9). In 1976 the Defense Science Board Task Force on Industrial Readiness reported on serious deficiencies in the defense industrial base which could potentially impact national security plans and objectives. General Alton D. Slay warned that ". . . it is a gross contradiction to think that we can maintain our position as a first-rate military power with a second-rate industrial base. It has never been done in the history of the modern world [58:16]." Specific problems uncovered were all directly related to declining productivity (40:1; 58:10; 64:12; 66:1-2; 71:57).

Problems in the Defense Industrial Base

Over the course of the past ten years, American industries in both the commercial and defense sectors have been plagued by a lack of productivity growth (11:1; 40:1; 56:210; 58:42-43; 66:1-2). Some productivity problems are traceable to reliance on antiquated plants and equipment, and declining investment in defense industry from the private sector. The situation is even more alarming because the result has been skyrocketing costs of modern weapons systems and excessive lead times in acquiring them. The increased prices have led to a loss of competitiveness of certain key industries, resulting in a decrease in available capital for the firms to modernize. In effect, we are faced with a circular trend which threatens to undermine the DoD's "ability to procure military equipment in a timely, efficient, and economical manner [58:13]."

The continued loss of industrial productivity has created considerable turbulence within the defense base, and evidence points to an actual shrinkage of that base (19:75-76). The majority of firms contracting with the DoD are owned by the private sector and, driven by the profit motive, they prefer the more lucrative business available to them from the stable, commercial sector (15:42; 58:12-14; 71:26). "Profitable growth is the success spur that motivates entrepreneurs to plan, to sell, to create, and to

take calculated risks with their ideas--and their money [60:66]."

Present investment trends from the private sector are indicative of their reluctance to invest capital in what they perceive to be a losing proposition. Instead, they continue to pursue "a strategy of low investment with high returns at the risk of long term growth [11:2]." Under the circumstances, the contractors consider a policy of low investment to be a good strategy. The government pays contractor costs, and the contractor has no incentive to keep those costs down. Additionally, the proliferation of old plants and equipment in the defense sector makes it extremely difficult for the government to determine what an item should cost. Even though doing business with DoD can be profitable, the structure of the defense industry is such that there are not a lot of suppliers for many defense items. Many factors combine to restrict entry into the defense business, including the huge start-up capital requirements, specific knowledge required about how to do business with the government, and to some extent the risk preferences of various firms. Recognizing this, the DoD is stressing long-range planning.

America's challenge is to react in time and take advantage of available (and appropriate) technologies. However, even the idea of exploiting available technology must be caveated to include recognition that just because a new technology is available does not mean it is economically

sensible. Figure 2.1 shows the growth of technology in the U.S. and the rate at which that technology has been implemented for the period from 1940-1980. American introduction of new technologies into plants and factories has not kept pace with the rate at which the technology has been developed, either in the defense or commercial sectors of the economy. The end result, as shown in Figure 2.2, is that U.S. industries have been losing ground in the productivity arena. Productivity in the U.S., as measured by relative growth of output per labor hour expended, has increased (see Figure 2.2), but the slow rate of improvement compared to other nations makes U.S. firms less competitive in the world market and threatens the continued viability of key defense-related industries (35:57).

The decreasing productivity growth rates are indicative of "the declining vitality of American industrial might," and even though the U.S. continues to lead the world in productivity, "the United States is dead last in productivity improvements among all industrialized nations of the world [58:16]." These problems are common to both the commercial and defense sectors of American industry, and even though the U.S. defense industry is the best in the world in terms of productivity, cost and technology, these positive aspects are a direct result of investments made in the 1950's and 1960's. We are currently relying on previous

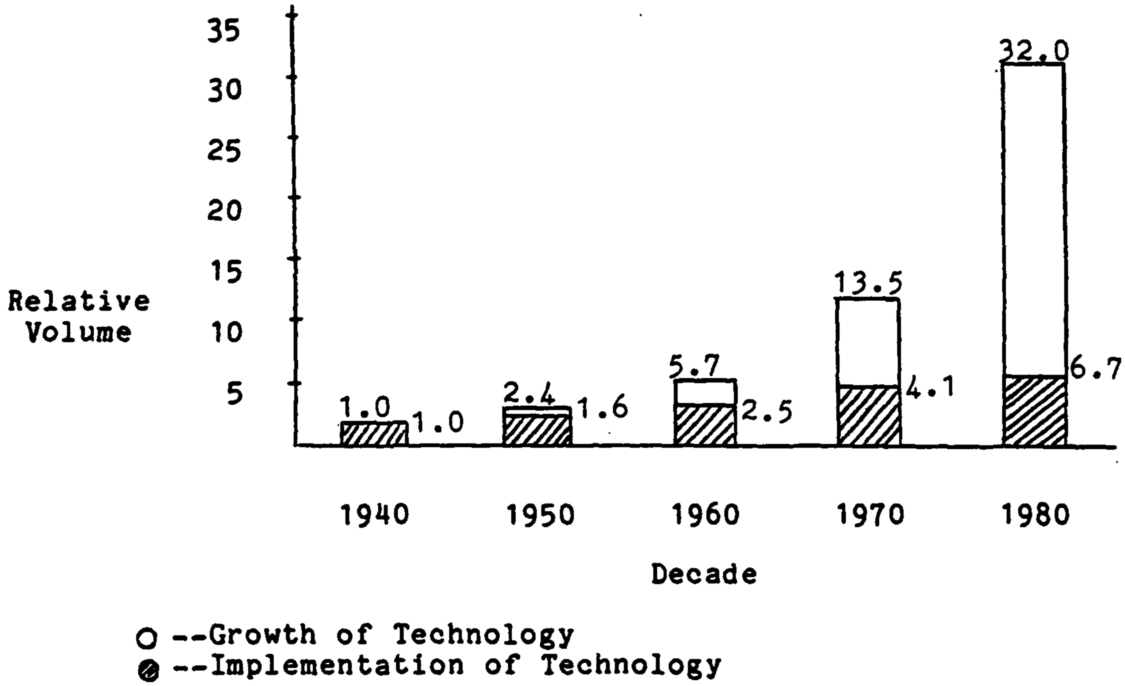


Figure 2.1. Implementation of Technology, 1940-1980 (Based on average 5% annual growth rate) (64:27)

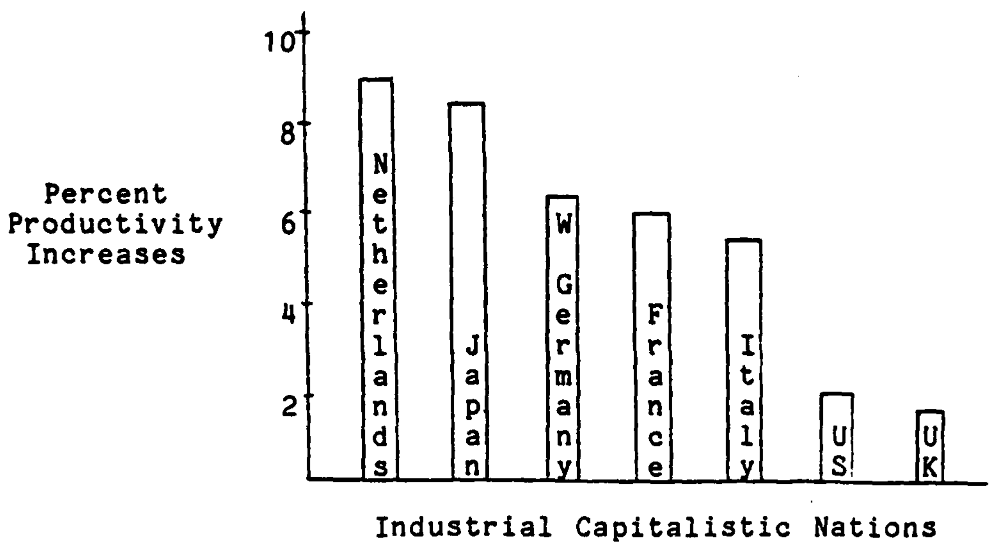


Figure 2.2. Growth Output Per Labor Hour, 1968-1978 (15:44)

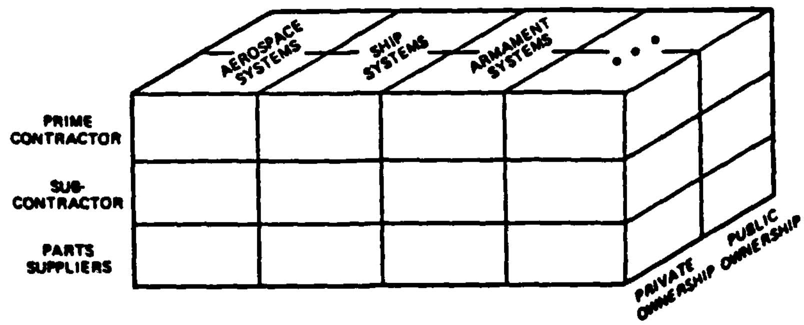
industrial improvements, but adverse trends in rate of investment in research and development and plant modernization could lead to problems for America's defense industry in the future (58:17). To understand how this situation could develop and how it can be countered, it is necessary to examine the structure of the defense industrial base (including the unique relationship between the government and prime contractors), the competitive market spectrum, and government/contractor incentives.

Defense Industrial Base Structure

Deterioration of the defense industrial base has three major impacts on the U.S., from a DoD perspective (50):

1. it reduces the wartime capabilities of U.S. Armed Forces,
2. it reduces the ability of American industries to surge, and
3. it results in costly peacetime operations.

Air Force efforts to reinforce the aerospace industrial base can be placed in two categories (2:i). The first of these categories is called contracting for productivity. Under this strategy, the AF uses contracting techniques, both innovative and traditional, to provide contractors with incentives to improve their productivity. Using the contracting for productivity approach, the contract is a tool through which the Air Force hopes to



NOTE: Lines separating these blocks are not as clear as the figure would seem to indicate. For instance, it is possible for a prime contractor in one sector to also be a subcontractor and/or supplier in another sector or other sectors.

Figure 2.3. The Composition of the Defense Industrial Base (35:3)

indirectly impact contractor investment decisions (and eventually productivity). The second category, which is the focus here, is known as Technology Modernization. In this program, contractors (and subcontractors) are given incentives to immediately modernize their facilities. The USAF's involvement in these incentives ranges from large "up-front" payments to a role of coordinating the sharing of different technologies among defense industry contractors.

Gansler views the defense industrial base as a cube (see Figure 2.3) with a dimension of contractors, a dimension comprised of the various systems, and a dimension of public or private ownership (35:3). One thing that should be noted from Figure 2.3 is the many different

combinations of the three dimensions (i.e., the many different blocks). Furthermore, for each block there are many sub-blocks. For example, the aerospace systems prime contractor can be further divided into many other blocks. Included in these various blocks are programs like the F-16, B-1, and A-10. Since each of the blocks and sub-blocks are unique in many respects, an understanding of the programs as entities and their complex interactions is required to apply Tech Mod. For example, the F-16 uses government furnished facilities whereas the B-1 does not. The F-16 has one prime contractor whereas the B-1 has four "associate" contractors (21). Both the B-1 and the F-16 have Tech Mod programs, but because of the differences in acquisition programs the individual Tech Mods are different. An important point to note here is that, while each program is essentially unique, there is some commonality in terms of Tech Mod design and type of information/data available from contractors.

A second area that must be understood in the defense base is the government/contractor (subcontractor or supplier) relationship. Figures 2.4 and 2.5 graphically display this relationship (21). An awareness of the intricacies of contractor ties can provide valuable insight for attempts at analyzing or describing those associations. For example, a modernization effort at a prime contractor's facility aimed at increasing "surge capability" would fail if the actual bottleneck occurred at the subcontractor

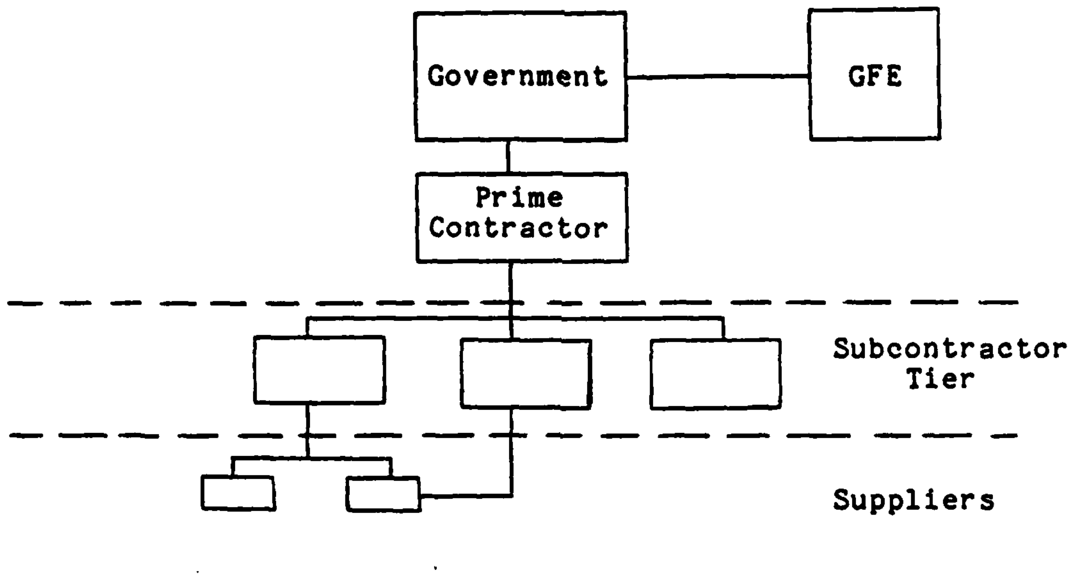
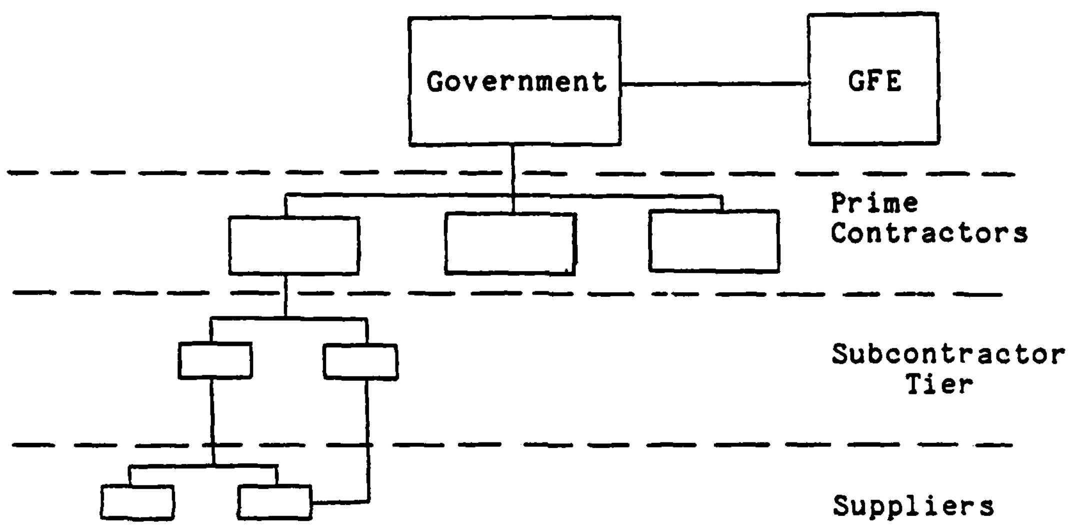


Figure 2.4. Government - Contractor Relationship
(One Prime Contractor)



NOTE: More than one contractor may use the same subcontractor or supplier.

Figure 2.5. Government - Contractor Relationship
(Multiple Prime Contractor "Associates")

level. However, by recognizing this structure and the relationship between prime and other contractors, the bottleneck (at the subcontractor level) should be discovered in Tech Mod's Phase I. There are many aspects of the defense industrial base that interact with Tech Mod processes. Only two will be explored here in order to provide the reader with some insight into the unique problems encountered when applying the Tech Mod concept.

AFCSR 800-17 (6:3) directs that Tech Mod be applied when "competitive market forces do not foster independent contractor modernization." In other words, when competition alone is insufficient to force contractors to improve productivity, increase efficiency and modernize, Tech Mod can be used to provide the requisite incentives. To understand how this applies, an understanding of the spectrum of competition within the defense base is required.

Competitive Market Spectrum

The defense industrial base spans the entire market spectrum of competition (see Figure 2.6) (21). This means that under some circumstances military procurement is competitive while in other instances it can be viewed as an oligopoly or monopoly situation. Stigler (65:5-12) identifies the requirements for perfect competition, but he notes that the abstractness of the concept forced economists to seek a more realistic definition. Perhaps more appropriate to a discussion of competition within defense-

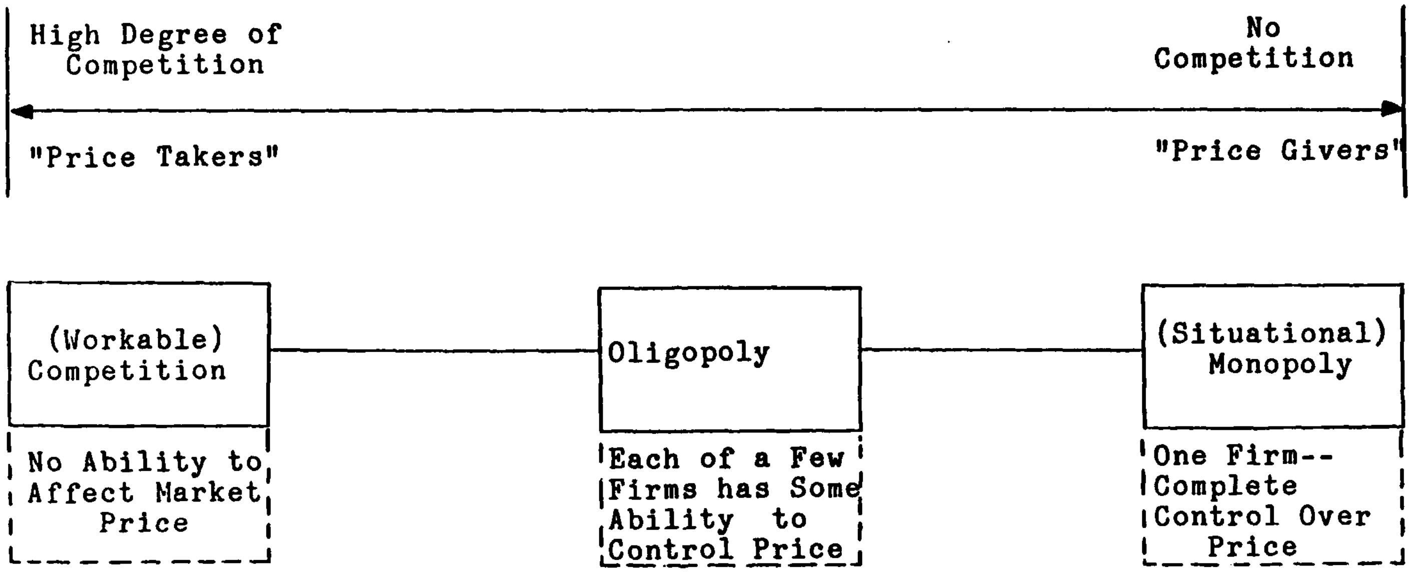


Figure 2.6. Market Structure Spectrum

related industries is the notion of "workable competition," first proposed by J.M. Clark (65:12). On the one end of the spectrum (see Figure 2.6), "workable competition" means that no single firm is able to appreciably affect market price by its actions; in the oligopoly situation there are a few firms in competition with one another, and each has some degree of control over market price; in a monopoly, there is only one firm supplying the item, and that firm has complete control over price (38).

Some acquisition items common to both military and civilian markets fall in the "workable competition" end of the continuum. Items in this area are easily procured goods such as foodstuffs and clothing. Moving along the competitive spectrum toward monopoly, firms have more control over the price at which they sell their product. An example of a product over which the seller has some ability to set price is the Inertial Navigations System (INS) used in various USAF aircraft. Only a few companies produce the INS--a classic oligopoly. Because there are few suppliers, companies that provide the item are price "givers," to a certain extent. Supplying hardware to the government under these circumstances can be quite profitable, but barriers to market entry and exit combine to maintain the status quo. Gansler (35:46-50) identifies 13 barriers to entry into, and 14 barriers to exit from, the defense business. The result is a situation where cost is greater than it would be in a competitive situation.

At the other extreme of the competitive continuum (opposite "workable competition") is the monopoly situation, which Blair and Kenney (18) identify as the "polar opposite" of perfect competition. "A monopoly is said to exist when a single firm produces a commodity for which there are no close substitutes [18:122]." From observation, it is known that there is an inverse relationship between the quantity of a particular good demanded and its price. This is known as the Law of Demand. Economic theory suggests that when a firm's size relative to the market is such that its production decisions affect the selling price of that commodity, that firm can increase its profits by artificially restricting output from what it would be in a competitive situation and thereby receive a higher price because of the law of demand (38). The more ability a firm has to affect market price, the closer it approaches a monopoly. However, much like the idea of perfect competition the concept of pure monopoly is nonexistent in the military context. No DoD suppliers are true monopolists because there are substitutes for all items the military services buy including major weapons systems. For this reason, the idea of a "situational monopoly" might more accurately describe those firms which supply major weapons systems to DoD. By choosing particular firms to supply major systems the military departments are in effect conferring monopoly status on that company in that

situation. The situational monopoly for that particular good exists for the life of the contract.

In general, as procurements approach the monopolistic end of the spectrum the selling prices of the goods increase. This assertion is supported empirically by a study of contracts that were switched from sole source to competition from 1963-1981. Prices were reduced in all cases, the reductions ranging from 10.8% to 56% (21). However, it is important to note that, even in an other-than-competitive situation, DoD's position as sole buyer of certain commodities endows them with a certain amount of leverage and bargaining power in price negotiations. This limits the seller's absolute control over price.

How then, is price set under these circumstances? In the competitive environment it is set in the market place. In that arena, companies have incentive to modernize their facilities to remain competitive. Since they must take what price is given, the only way to increase profits is to become more efficient. In other than the competitive environment, the price is set by the balance between power wielded by the single buyer and the single seller. With the proper balance between the two, a price of effective competition can be reached (21). Intuitively, it seems that if contractors would modernize their facilities production costs (i.e., variable costs) would decrease and profits would increase. However, defense contractors have not

rushed to invest in facility modernization because capital investments of the magnitude required would produce insufficient return on investment (ROI). ROI is the rate of return above which funds would not be invested, and contractors are not investing because facility modernization would reduce their profits, at least in the short run. To understand the capital investment dilemma more clearly, it is necessary to examine both government and contractor incentives.

Incentives

Government

Government incentives are based on direction from the top--from those who control and those who manage the acquisition process. The DoD acquisition improvement program (DAIP) addresses many of the issues which have contributed to capacity shortfalls and long delivery times. Specifically, DAIP focuses on those characteristics which have lessened industry's desire to invest in new capital equipment (20:35). Former Deputy Secretary of Defense Thayer stated a "team relationship" between DoD and industry should be fostered to help eliminate long-term problems, and the current Deputy Secretary of Defense (DepSecDef Taft) has made no move to change this policy (21; 29:3). Assistant Commerce Secretary Merrifield said, "the focus of my job is on productivity and reindustrialization [14:75]." Dr.

Keyworth, science advisor and director to the White House Office of Science and Technology, believes that private industry should lead the U.S. back to a competitive stance (68:58). Further, he stated ". . . the free market is the . . . most efficient means of allocating resources [73:42]." Guidance such as this is reinforced in the Defense Acquisition Regulation (27:1-300.1) and the Federal Acquisition Regulation (28:7.105), which both point to competition as the preferred method of acquisition. Unfortunately, many times these objectives are obscured by the government's short-term planning horizon (67:25). In a sense the government as the buyer of military hardware fosters the low-investment strategy of defense contractors. As Gansler (35:32,46-47) points out, the government buyer is relatively insensitive to price, concentrates acquisition on a limited number of systems, and has unstable demand. The result is limited or no incentive for contractors to invest in productivity and efficiency improvements.

<u>Contractor</u>

Economic research on technological change keys on two areas. First, technological innovation generates productivity growth, and research and development (R & D) dollars determine technology advancement. Second, firms tend to underinvest in R & D because knowledge is stolen, payoff is uncertain, and many firms are too small (52:814-815). Other reasons for lack of investment include high

inflation, high interest rates, too much government regulation, unfavorable tax policies, and short-run profit maximizing strategies (40:11). The one main reason for lack of investment echoed in almost every study was lack of long-range planning (37:1-1).

According to a recent study (40:96-97) on Tech Mod, four factors were identified as the most significant capital investment incentives among twenty defense contractors. They are:

1. improve or maintain a reputation for producing quality products,
2. reduce risk,
3. reduce uncertainty, and
4. improve short-term cash inflows on modernization capital investment.

Profit 82, an AFSC study, concluded "the major determinant of capital investment is expected return a contractor can realize [8:47]." The study further stated that profit by itself will not induce capital investment. The greatest concern of industry is recovery of investment with a reasonable return. Secondary considerations were competition, maintaining market share, growth, and technological advancements (8:53). This 1982 study continued, stating government policy on contract award did not provide enough return for the risks involved to stimulate capital investments (8:56).

Part of the problem is that disincentives for increased efficiency exist. For example, if a company produces a product that costs $100 and they received a 10% return on the product, their profit is $10. Now assume they invest a large amount of capital in facilities and thereby reduce production costs to $70. The new profit at a 10% return is $7. The company just lost $3 per unit in profit for taking a risk, investing their money, and becoming more efficient. Government attempts to induce contractor investment must respond to this issue of "lost profit" (54). A special productivity factor is currently applied that raises the profits of the company above what they would have made before the modernization. However, the Profit 82 study points out this productivity factor is not effective because it provides too low a return compared to the risks involved (8:58).

At issue then is the problem of reconciling government and contractor incentives. Part of the problem stems from the noncompetitive nature of the contractor market which in turn affects the kinds of contracts the government can negotiate. On the one hand the government wants to provide cost-effective national security; and on the other, defense contractors are concerned with their reputations, their short-term ROI, and the risk and uncertainty inherent in defense business. Tech Mod possesses the potential to serve as the focus for reconciliation.

Toward a Solution: Technology Modernization

Background

Tech Mod is one DoD solution to a defense industrial base that is perceived to be "ailing," and to the escalating costs of weapons systems (54). Gansler (35:4) states:

> the industrial base of the U.S. defense is becoming both economically inefficient in production of defense material and strategically unresponsive in terms of the production speedup required to meet an emergency.

The essence of a report presented to the Committee on Armed Services on 31 December 1980 stated ". . . there has been a serious decline in the nation's defense industrial capability that places our national security in jeopardy [58:iii]." As can be seen in Figure 2.7, the U.S. productivity growth rate when viewed relative to the other major industrial powers has significantly decreased over the period from 1960 to 1979 (9:3).

The overwhelming need to improve defense base productivity was a major challenge facing the DoD as we entered the decade of the 80's. "Some economists have computed that technology is responsible for 88% of our growth in productivity [67:22]." Acknowledging the importance of this symbiotic relationship between technology

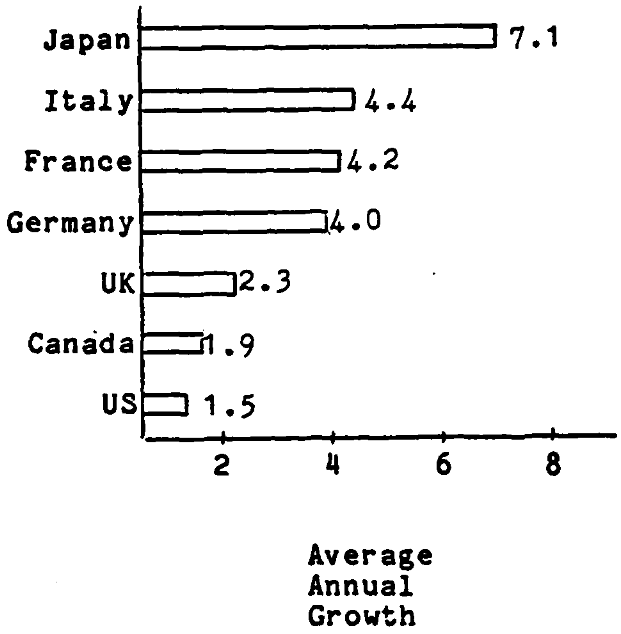


Figure 2.7. International Productivity Growth, 1960-1979, Total Economy (9:3)

and productivity, in 1978 the Air Force embraced what has become known as the AF Technology Modernization (Tech Mod) program. The original plan was conceived by General Dynamics, the F-16 Systems Program Office (SPO), and AF Wright Aeronautical Laboratories (AFWAL) as a strategic (i.e., long-range) attempt to improve contractor technology and facilities, reduce F-16 cost and lead time, and improve a portion of the industrial base. In concert with General Dynamics, the AF adapted Tech Mod to suit specific Air Force needs, and what emerged was a "framework for a cooperative Air Force/contractor venture [intended] to systematically enhance productivity and reduce acquisition costs [2:3]."

The keys to increasing productivity are capital investment and technology, and Tech Mod is the vehicle through which the Air Force is attempting to modernize select portions of the defense industry (30:1-1; 66:2). The ambitious goal of Tech Mod is "to improve the overall health of the industrial base through implementation of manufacturing technology and increased capital investment [2:1]." Resultant improvements in productivity will theoretically benefit both the Air Force and the private sector in terms of reduced costs, higher quality, decreased lead times, decreased consumption of critical, strategic materials, and increased competitiveness of U.S. firms in the world market (2:4).

According to the Defense Industrial Base Panel (58:41):

> . . . almost all government procurement actions involve some degree of risk to both the government and the contractor. The challenge to defense procurement management is to minimize risks while minimizing expenditures. The challenge to business management is to minimize risks while maximizing profits.

The Air Force is determined, through the Tech Mod program, to meet this challenge. Technological development generally occurs in an industrial setting, and Tech Mod is essentially an Air Force/contractor partnership designed to systematically transfer new and existing technologies from

the lab to the production floor at contractor facilities. A corollary to this is the requirement that sufficient capital investments accompany the new technologies to insure their implementation (2:ii; 39:576; 61:1014). An important aspect of the partnership concept is the idea that both the contractor and the Air Force must benefit from the Tech Mod, and both should share the risks associated with the venture. The Air Force and the contractor benefit by sharing savings. Contractual incentives allow the firm to attain an acceptable rate of return, and at the same time they share the risks associated with modernization with the USAF (30:2-4). The government "shares the risk" either by providing seed money to get the Tech Mod underway, or by inserting an indemnification clause into the contract so that the firm will be reimbursed if the project is cancelled prematurely. Additional contract provisions insure future contractor profits won't be negotiated away, and by committing themselves to Tech Mod, contractors increase their competitiveness through improved productivity (2:9). The recognized potential of Tech Mod to induce contractor capital investments has led to increased consideration of the technique.

Tech Mod Structure

Policy guidance to the Air Force Systems Command contracting community states, "Tech Mods will be considered early in the acquisition cycle as part of acquisition

strategies . . . [7:Atch 1-1]." AFSCR 800-17 (6:3-4) directs that Tech Mod be used in two instances:

1. when competitive market forces are insufficient to foster independent contractor modernization, and

2. when significant benefits (such as cost production, elimination of production bottlenecks, improved quality and reliability, conservation of strategic or critical materials, or improved surge capability) can be expected to accrue to the government.

A Tech Mod can originate in one of four ways. First, it can be required by a program's Request for Proposal (RFP); second, during the course of contract development the AF and contractor can jointly agree to pursue Tech Mod; third, a contractor can submit an unsolicited proposal; and finally, it can develop through a Sources Sought Synopsis, RFP, or competition (2:6). Any contractor who does business with the Air Force is eligible to participate in the Tech Mod program.

When a program is selected for Technology Modernization, it is accomplished in a three phase effort (see Figure 2.8). In Phase I a factory analysis is completed which evaluates contractor facility needs and identifies candidate technologies. A "business deal" between the contractor and the AF is negotiated at the end of Phase I, and it specifies ground rules for the final two phases. During Phase II, implementation plans are drawn up

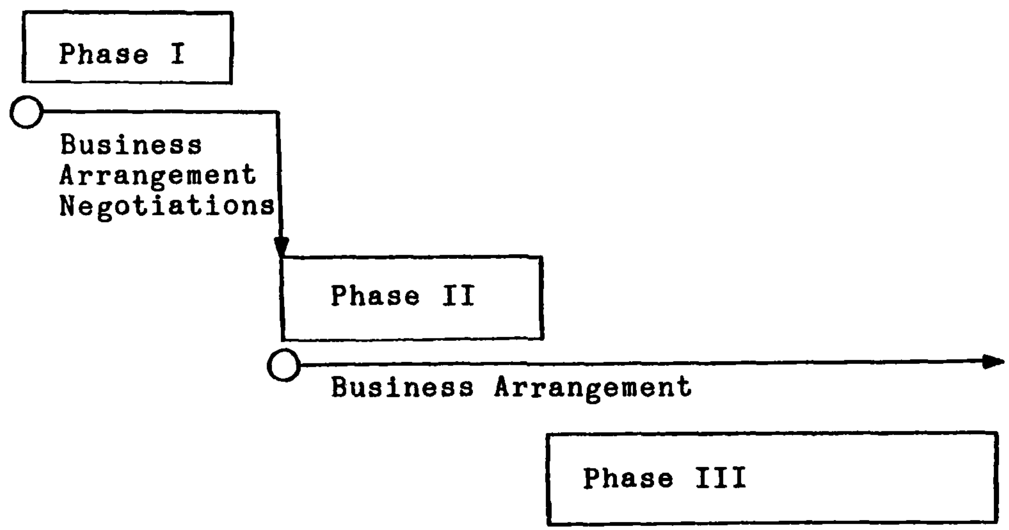


Figure 2.8. Tech Mod Phasing (2:2)

and enabling technologies are developed. Phase III is the actual implementation of the Tech Mod and includes purchase and installation of capital equipment by the contractor (2:1). The end result will be improved productivity within the defense industrial base brought about by a combination of technology and capital investment.

Two Approaches to Tech Mod

As noted above, Tech Mod was conceived as a means of providing incentives for defense contractors in the aerospace industrial base to invest in modernization of their facilities, equipment, and production processes. The original objective of the program was to revitalize the aerospace base by concentrating on key firms. However, the success of early Tech Mod endeavors contributed to its widespread acceptance by the acquisition community, and it is currently regarded as a viable approach to improving the overall health of the defense industrial base. Program success has led to a certain degree of proliferation, and indeed, each of the services has established a Tech Mod-like program under the aegis of the DoD Industrial Modernization Incentives Program (IMIP). Since Tech Mod is an Air Force IMIP program, "Tech Mod" will continue to be used herein, when referring to the Air Force program. The Army program is called Industrial Productivity Improvement (IPI), while the Navy program is simply known as IMIP (43).

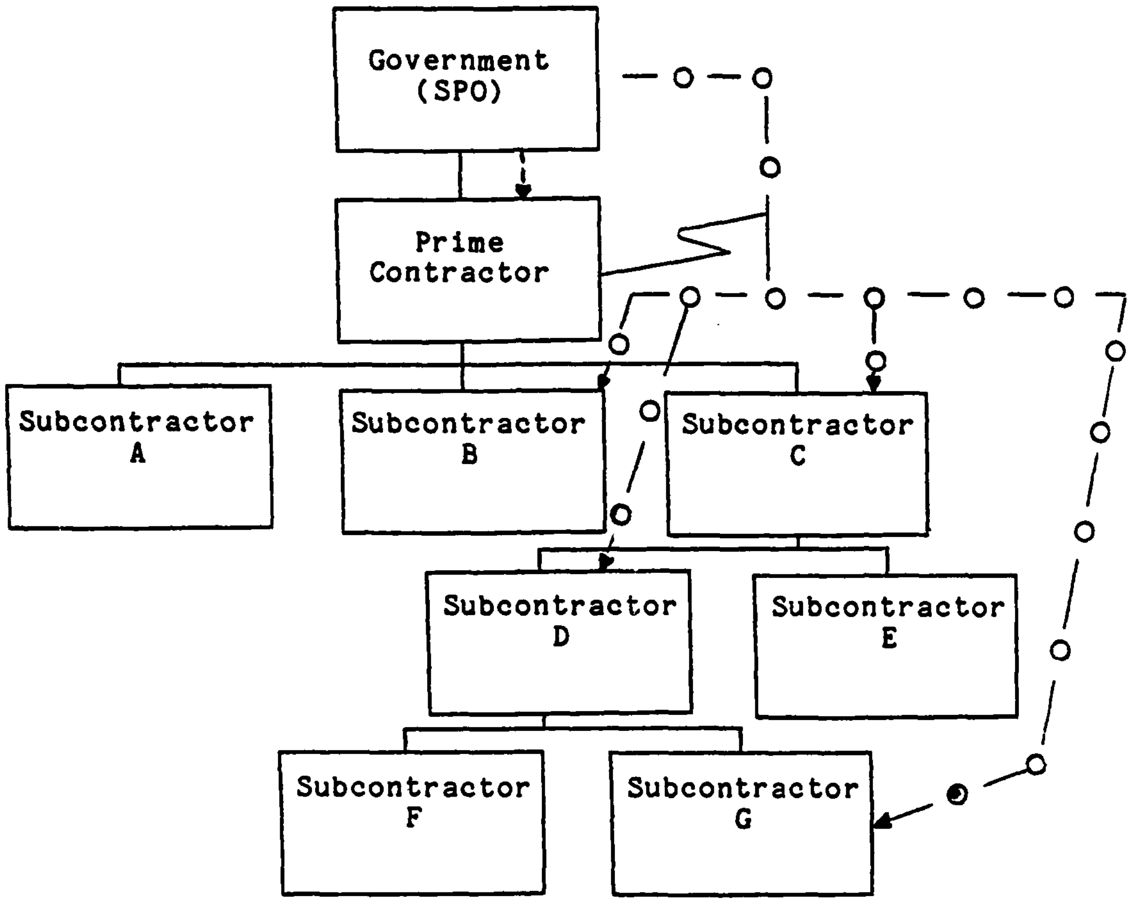
In addition to DoD-wide acceptance of the Tech Mod concept, the use of Technology Modernization has expanded within the Air Force as well. Air Force Systems Command (AFSC) guidance requires SPOs to consider Tech Mod for all major system acquisitions, and the Centralized Tech Mod Management (CTM) office within the Aeronautical Systems Division (ASD) of AFSC conducts annual analyses of the production base to identify thrust areas for potential Tech Mods. Air Force emphasis on Tech Mod has led to a situation where two distinctly identifiable approaches to modernization exist. The two approaches are classified as:

1. vertical, and
2. horizontal.

These approaches are mainly one of perspective, and the vertical approach is normally associated with SPO Tech Mods while the horizontal approach is the one generally pursued by the ASD Centralized Tech Mod Management office.

Vertical Tech Mods. A vertical Tech Mod effort, as depicted in Figure 2.9, describes the situation wherein the government party (generally a SPO) establishes a Tech Mod with a prime contractor and/or associated subcontractors. The goal, as with all Tech Mods, is to provide adequate incentive for targeted firms to invest in modernization.

This perspective is called the "vertical" approach because it is directed only at firms involved in the



--Denotes Tech Mod contract between government and prime.

--Denotes management by the prime (may or may not exist).

--Denotes Tech Mod program with subcontractors.

Figure 2.9. Vertical Tech Mod

production of the major system managed by a SPO. For example, Figure 2.9 shows that the SPO has a Tech Mod contract with the prime contractor (represented by the dashed line) and also with subcontractors B, C, D, and G (represented by the dashed-dotted line). Vertical Tech Mods which extend to the subcontractor tier "are generally developed through and managed by the prime system contractor [2:14]." The subcontractor Tech Mod program established by the F-16 SPO is a representative example of the situation where the prime system contractor (General Dynamics Corporation) has accepted responsibility for managing a Tech Mod program with selected (General Dynamics-associated) subs.

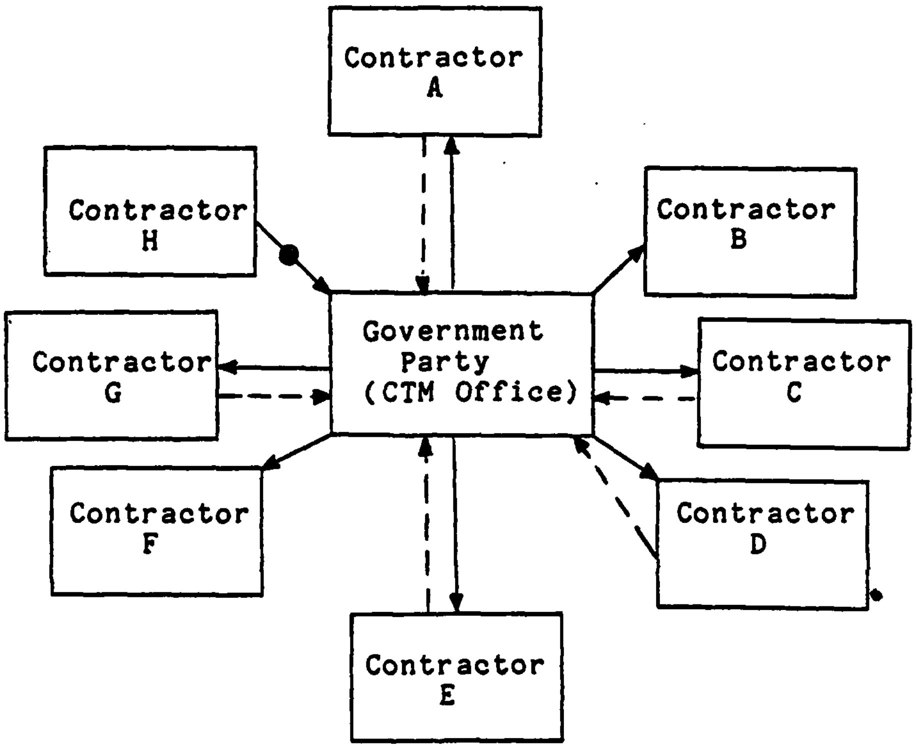
The vertical approach to Technology Modernization has been successful, but is somewhat limited in scope and impact. Only certain, select businesses are "targeted" to receive the benefits of Tech Mod under the vertical approach, and only a tiny segment of the aerospace industrial base is affected (2:14).

Horizontal Tech Mods. The greatest long-term impact of Tech Mod is not that it can effectively lead to modernization of individual firms within an industry but rather that it has the potential to "drive" modernization of whole industries. Recognition of the possible implications of Tech Mod for the entire aerospace industry led to development of a "horizontal" approach, and establishment of

a Centralized Tech Mod Management office within ASD to administer horizontal Tech Mods. The CTM office's role is to ensure that the Air Force realizes maximum benefits from its modernization initiatives. Through application of the horizontal approach, that office can achieve the "broad based 'cross-cuts' which can coordinate productivity enhancement and facilitate technology transfer throughout an entire [industry] [2:14]." The CTM office is not strictly limited to Tech Mods of the horizontal variety, and will consider vertical Tech Mods if a contractor's business base is too diverse for a single SPO (2:14). However, the majority of CTM office endeavors are concentrated horizontally.

Figures 2.10 and 2.11 depict the horizontal approach to Technology Modernization. Figure 2.10 shows how the process is initiated by the government party (CTM office) sending out modernization Request for Proposals to firms in a target industry or sector of the aerospace base. In the example, not all businesses contacted responded to the RFP; however, one firm not notified (Contractor H) did submit an unsolicited proposal. Figure 2.11 shows that, after evaluating proposals, the CTM office selected contractors A, C, D, G, and H for Tech Mod (Phase I) contracts.

This is an oversimplified account of the horizontal Tech Mod process (as was the earlier depiction of vertical Tech Mods), but it demonstrates the general nature of the



--Denotes RFP sent by government.

--Denotes Contractor response (proposal) to RFP.

--Denotes unsolicited proposal.

Figure 2.10. Government Contacts "Targeted" Industry

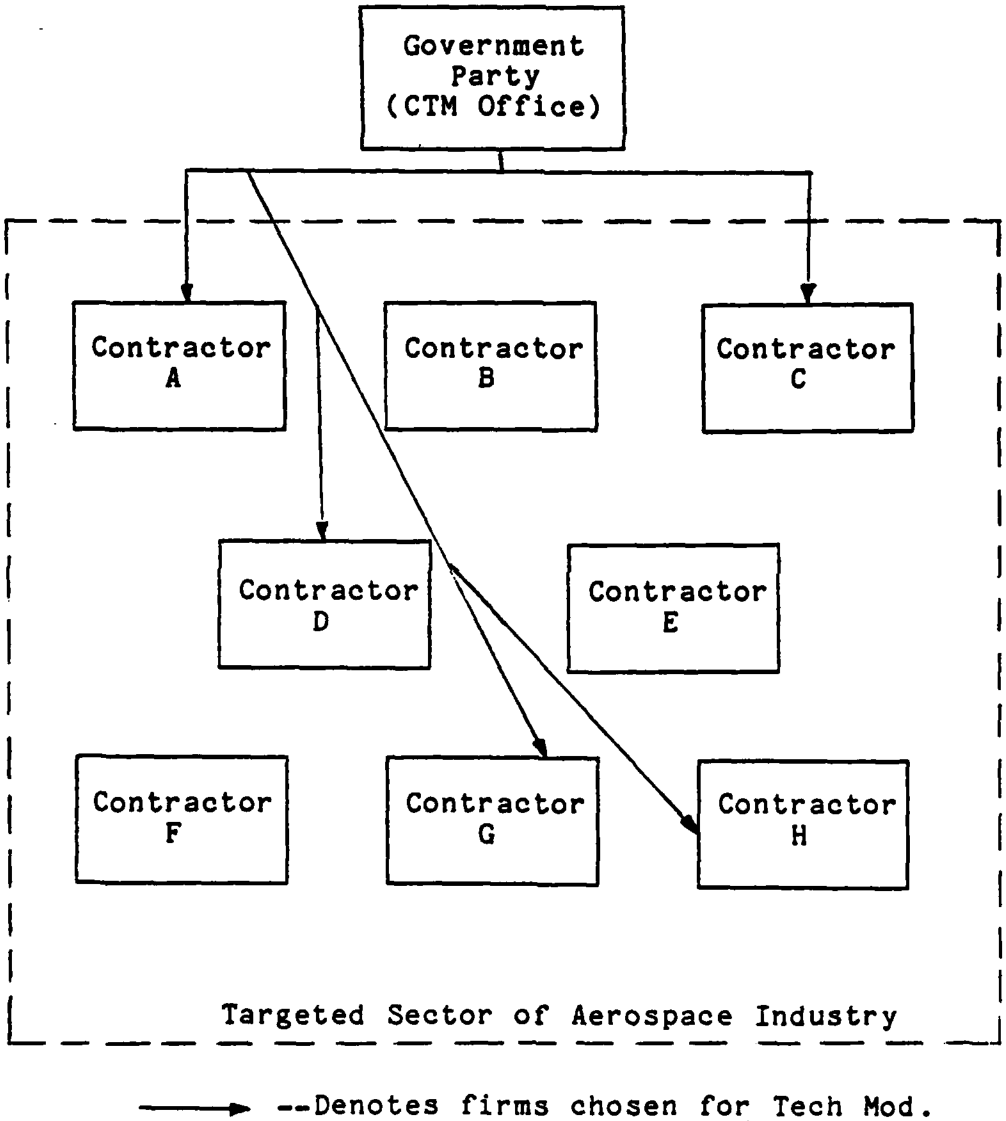


Figure 2.11. Horizontal Tech Mod

approach. The case analyses of Chapter 4 provide expanded views of the vertical and horizontal Tech Mod perspectives by analyzing specific programs associated with each.

Conclusion

When the free market forces are in effect, as in the situation described as "workable competition," there probably is not a need for Tech Mod because ". . . competition in the open markets . . . is the most important incentive for investment by industry [61:1014]." When a situation resembling realistic competition exists, the lowest cost producers are the ones who will survive and thrive in the market (38).

However, as related above, the firms supplying major systems to the services approach monopoly conditions (i.e., the concept of situational monopoly). Under these circumstances, contractors may not have sufficient incentives to invest in modernization. Tech Mod has demonstrated its promise as a vehicle for inducing defense suppliers to modernize. The potential widespread application of the concept can substantially affect the amount of investment, and eventually the productivity, of key defense-related firms. For this reason, an understanding of the decision processes involved in Tech Mod selection is imperative. The remainder of this thesis examines Tech Mod decision making, culminating in a

suggested procedure for supplementing or aiding that decision process.

III. Research Approach

Chapter Overview

In conducting this research, it was necessary to identify and clarify relevant issues concerning the Tech Mod decision process. The inquiry led to consideration of three areas suggested by Jahoda, Deutsch and Cook (28:34):

1. a review of all pertinent literature,
2. interviews with experienced practitioners, and
3. analysis of specific, "insight-provoking" cases.

The above approach was modified to more specifically address the problem explored by this study, and the research design shown in Figure 3.1 was developed.

Preliminary Investigation

In the first stage of this study, a preliminary familiarization investigation was conducted to provide an overall perspective on Tech Mod and to specifically identify areas of useful research. The investigation consisted of two steps:

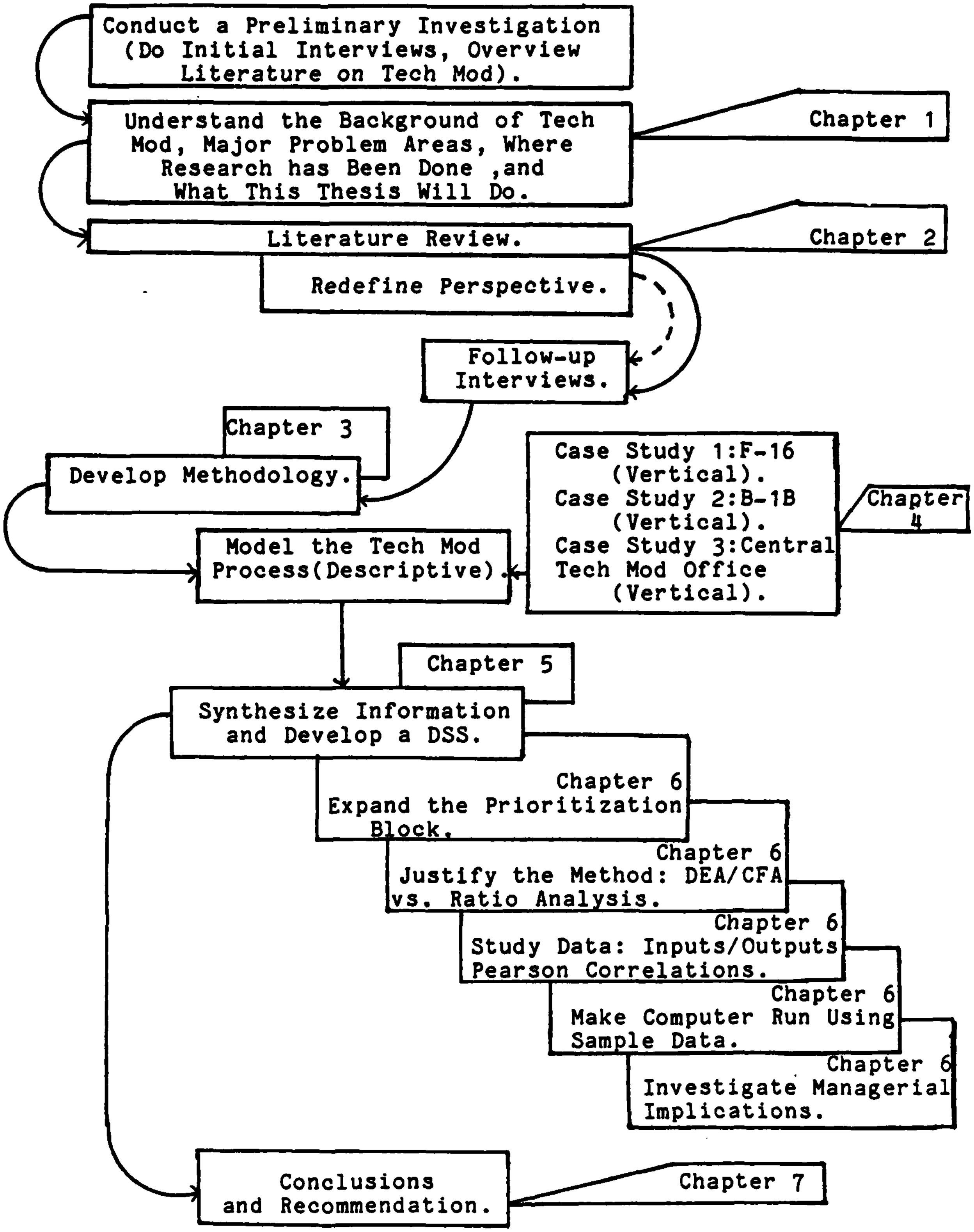


Figure 3.1. Research Methodology

1. a literature survey, and
2. interviews.

The literature survey in the preliminary investigation was very limited in scope, and was accomplished to gain insight into the background and general issues surrounding Tech Mod. For this reason, efforts were concentrated on several government publications concerning Tech Mod and the defense industrial base.

The interviewees were selected based on the following criteria:

1. expertise, and
2. possession of a broad-based knowledge of the Tech Mod program.

Since Tech Mod is relatively new and each of its programs is somewhat unique, there were few individuals who met the criteria. Therefore, interviewees were chosen from the policy-making office for all AF Tech Mod programs (AFSC/AIM) and the Centralized Tech Mod office (ASD/PMDP).

Information obtained during this familiarization process directed the focus of this thesis toward development of a Decision Support System (DSS) to aid the Tech Mod process. Keen and Morton (42:174), however, suggest before any computer support can be designed one must accomplish a five step "predesign cycle":

1. monitor and describe the current decision process,

2. determine the key decisions,

3. define the "normative model,"

4. compare the descriptive and normative models, and

5. select areas for support.

Monitor and Describe the Current Process (Chapters 2 and 4)

Literature Review. In order to explore the possibility of developing a DSS to aid Tech Mod managers, a literature review was conducted to better understand the Tech Mod background, to determine where research had been done, and to determine what this thesis could accomplish. Three aspects of the Tech Mod environment were important to this study:

1. an historical perspective of the defense industry,

2. the structure of the defense base, and

3. government and contractor incentives.

The historical perspective was included to provide a background and general comprehension of the problems Tech Mod was created to solve. A basic understanding of those problems could possibly lead to new and innovative solutions. Since most Tech Mods are unique and the structure of the program allows a large latitude in application, new approaches were important to consider.

It was important to study the structure of defense industry to discern government/contractor and contractor/industry relationships. This section of the literature review revealed information about both the problems Tech Mod attempts to solve and the structure within which the program must operate.

Finally, since the premise behind Tech Mod is to incentivize industry, the program can only be effectively applied when government <u>and</u> contractor incentives are understood. The Air Force manager must base decisions on perceived benefit to the government and at the same time motivate the contractor to invest. Accordingly, the final sections of the literature review detail government and contractor incentives, and a description of Tech Mod.

Surprisingly, the literature contained very little information on the Tech Mod decision process. However, the background information on Tech Mod provided the basis needed to begin the predesign cycle as described by Keen and Morton (42:174). Since the literature was barren in reference to the decision process, interviews were necessary to accomplish step one, which was to monitor and describe the current decision process.

<u>Interviews.</u> To obtain the most current information concerning Tech Mod, personal interviews were conducted with experts in the field--individuals currently involved in Tech Mod in a decision making capacity. Because "only a very

small proportion of existing knowledge and experience is ever put into written form," interviews allow researchers to tap "a reservoir of experience which could be of tremendous value in sensitizing the social scientist to the important influences operating in any situation which he may be called upon to study [28:36-37]."

A semi-structured approach was used for the expert interviews. Before a scheduled interview, a list of questions was prepared based on information obtained in earlier phases of the research. These questions were intended to substantiate information compiled in the literature review and possibly to pinpoint areas not yet investigated.

In the initial portion of the interview, open-ended type questions were asked. This technique was intended to allow free expression of ideas by interviewees so they could discuss what they felt to be most relevant. As the interview progressed, each main point from the list of questions that had not been covered was specifically addressed. This procedure was necessary to ensure that the experts did not neglect any areas they believed to be "understood," or "common knowledge." Furthermore, those interviewed were asked to make comments on any aspect of Tech Mod they felt pertinent; and if they wished, their names would not be associated with controversial comments.

This particular approach to interviewing was used because it allowed an unimpeded flow of information, it provided ample opportunity to request clarification or amplification of certain points, and it circumvented any potential resistance a rigid structure might produce. Once all interviews had been completed, enough information had been gathered to construct descriptive models describing actual Tech Mod decision making processes. The models developed covered both major approaches to Tech Mod, that is, both the horizontal and vertical approaches.

Determine Key Decisions/Develop Normative Model/Compare to Descriptive Model (Chapter 5)

From the descriptive models, key decisions were extracted and formulated into a generic normative model (steps 2 and 3 of the predesign cycle). In an attempt to keep the model generic, two starting paths were required to depict the unique aspects of both the horizontal and vertical approaches. Furthermore, the normative model was purposely designed to be both iterative and modular--iterative in the sense that the normative model was changed when comparison to the descriptive model revealed an improvement could be made (step 4 of the predesign cycle); modular in the sense that a decision maker may expand or reduce a "block" without affecting the "blocks" around it. This independence of blocks allows one to implement and improve on the process in manageable increments.

Select Areas for Support (Chapter 6)

Chapter 6 demonstrates how a block may be expanded (step 5 of the predesign cycle). Expansion of the prioritization block could actually fill a thesis itself; and recognizing this, the development herein had more of a macro view to facilitate understanding. Just as the normative model can serve as a baseline for future research, so can the prioritization process. The prioritization technique was developed from three ideas by Farrell (32). Farrell's first idea, "technical efficiency," has been developed into a linear program (22) and shown to be a useful approach in rating the efficiencies of not-for-profit organizations (16; 25; 59; 63). The concept of an organization's technical efficiency, which is determined from comparison with a subset of efficient organizations, is used herein as a "stepping stone" to the idea of "overall efficiency" which rates all units relative to one another. Research was lacking in Farrell's two concepts of "price efficiency" and "overall efficiency"; consequently, more time has been devoted to their explanation and development. The concepts are developed sufficiently for the manager to understand and are referenced enough for the designer to implement.

The structure of the prioritization block (and Chapter 6) is arranged to present a logical flow similar to what a decision maker might use. The first part of the chapter

explains why linear programming was chosen as a basis of prioritization. Following that, a logical sequence for prioritization is developed from the study of inputs and outputs through the running of sensitivity analyses to arrival at a ranking scheme satisfactory to the decision maker.

In addition to explaining the important concepts, for means of illustration some actual data from Tech Mod programs were collected and processed with a computer prioritization program. In some computer runs, extra data were added to fill in areas where complete data were not available. Data additions are annotated.

Finally, several conclusions were drawn, recommendations were made, and areas for future research were identified.

IV. Tech Mod Decision Making: A Descriptive View

Chapter Overview

This chapter contains a description of the decision-making processes by which programs and projects were (and currently are) selected to participate in Tech Mod. Included are case analyses of program or project selection decisions for both the vertical and horizontal approaches to Tech Mod (as described in Chapter 2). The vertical perspective is examined as it relates to Tech Mod programs established at the Systems Program Offices for the F-16 and the B-1B. The horizontal perspective is examined by describing the decision process of the Centralized Tech Mod Management Office. The decision making processes reviewed and developed as flow diagrams herein are in actuality the descriptive models of the Tech Mod decision process. These descriptive models form the necessary basis for development of the normative model of Chapter 5, which incorporates a proposed decision support system.

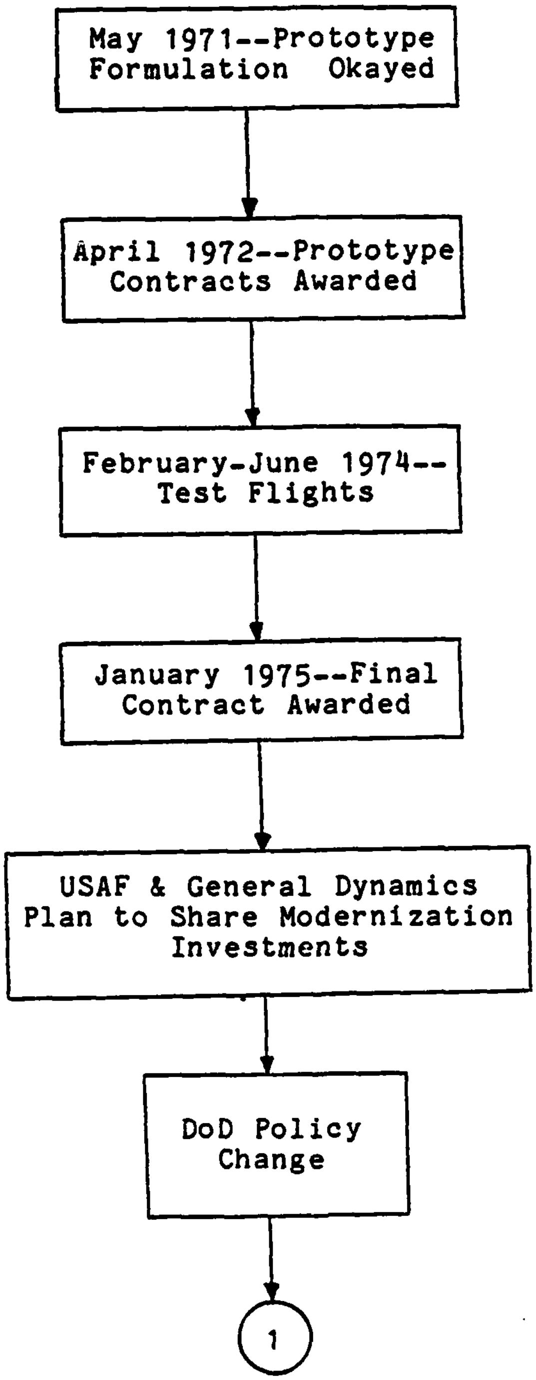


Figure 4.1(A). The F-16 Tech Mod Decision Process--Early History

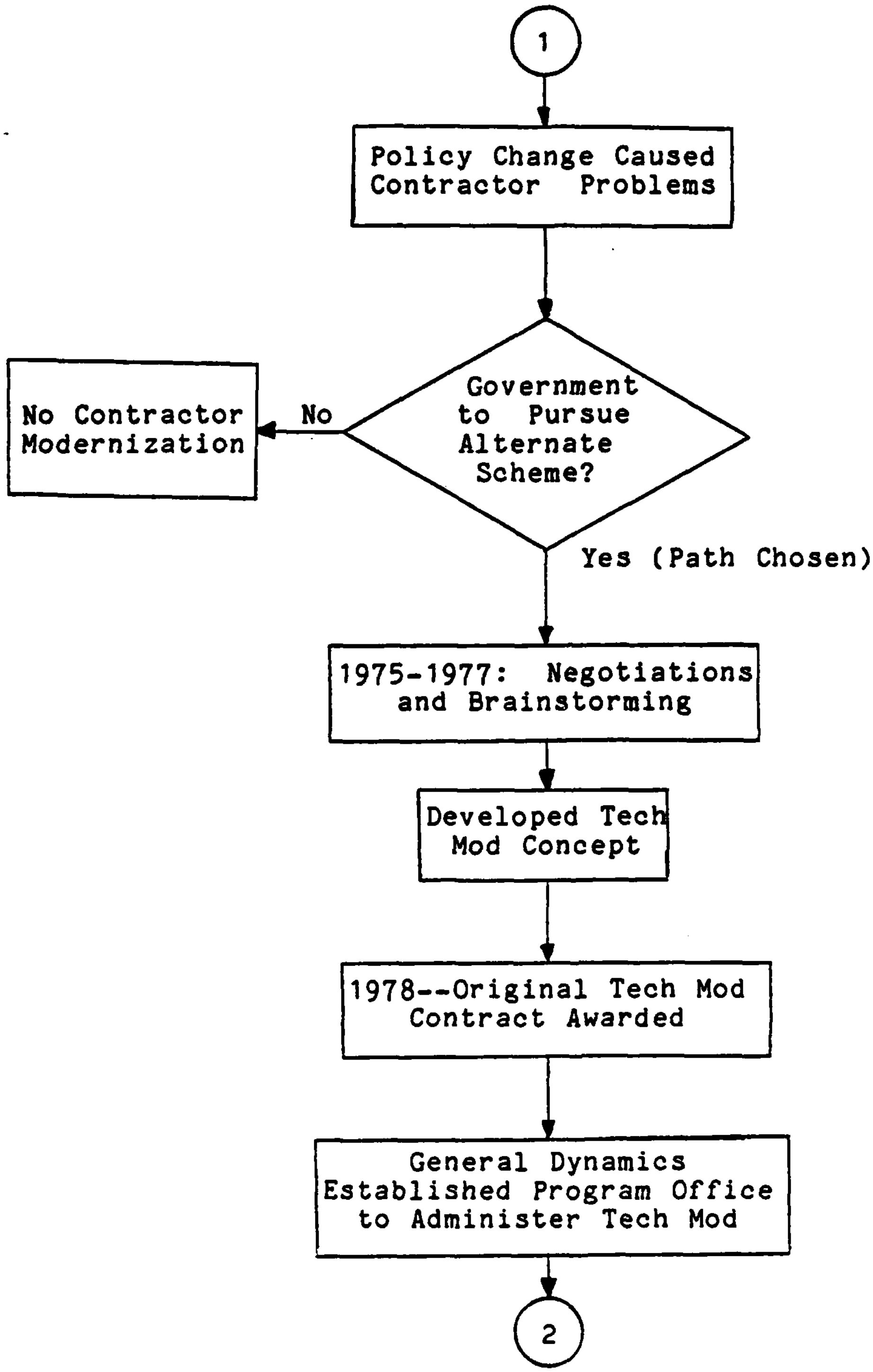


Figure 4.1(B). Conception of Tech Mod

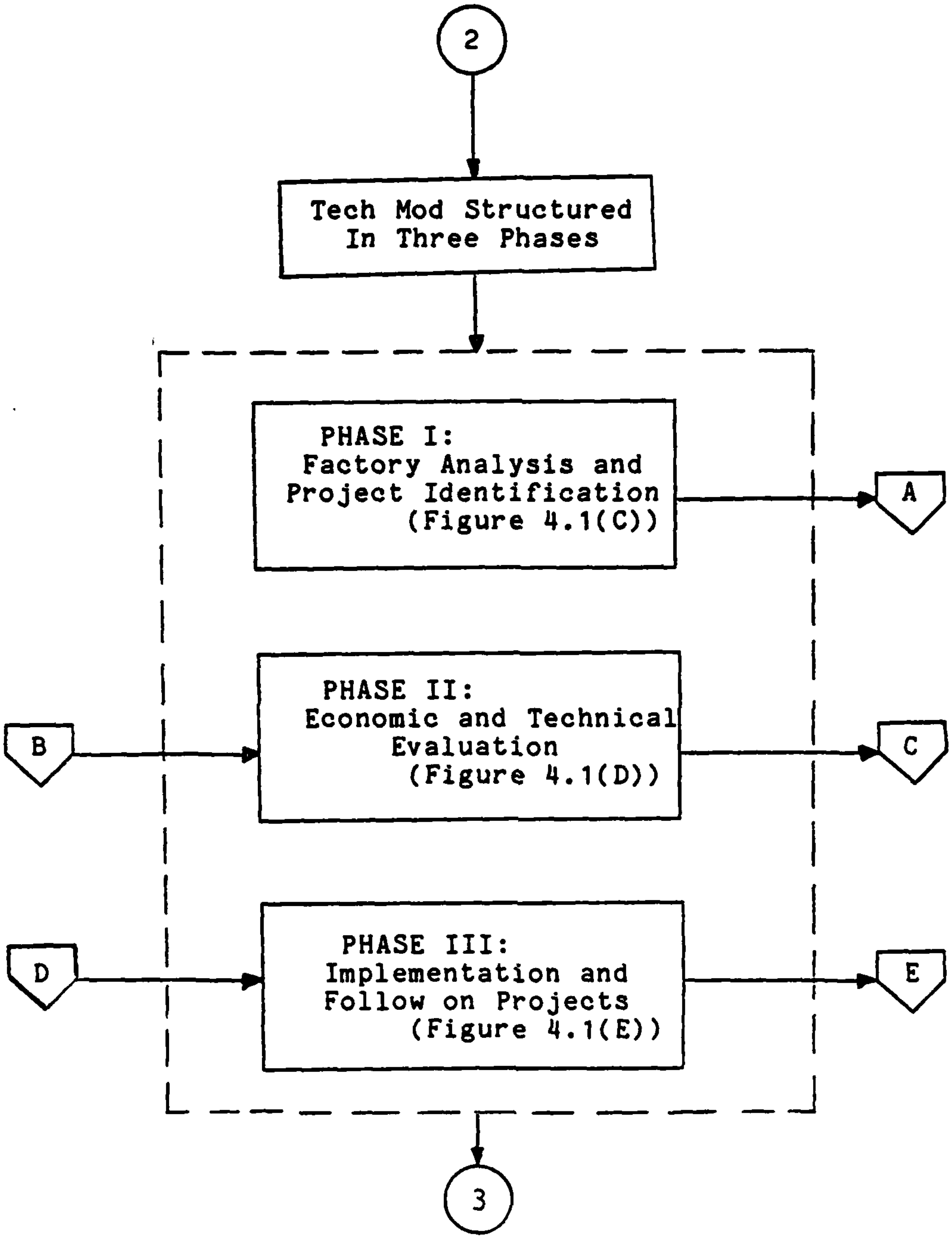


Figure 4.1(B). Conception of Tech Mod (Continued)

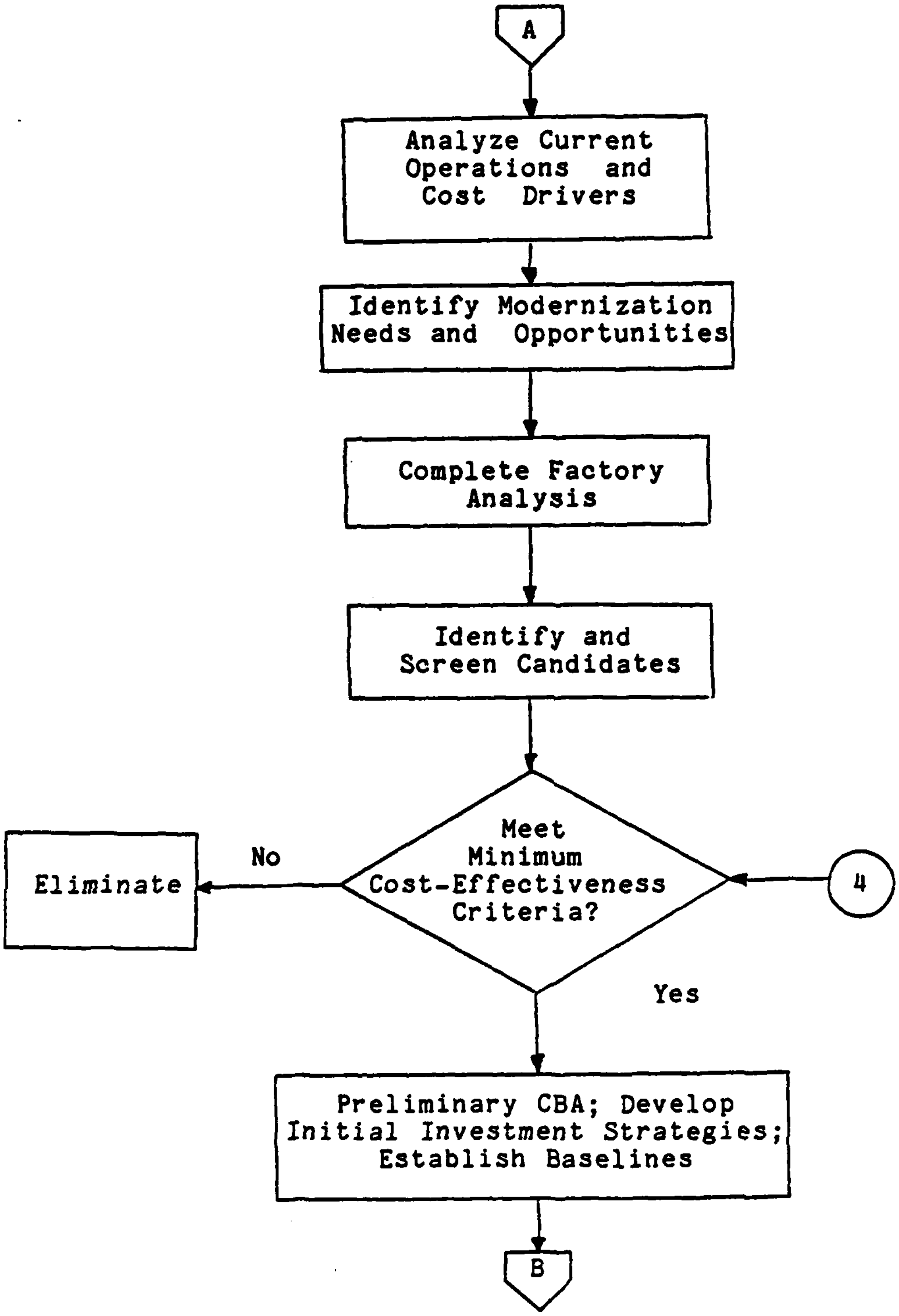


Figure 4.1(C). F-16 Tech Mod, Phase I

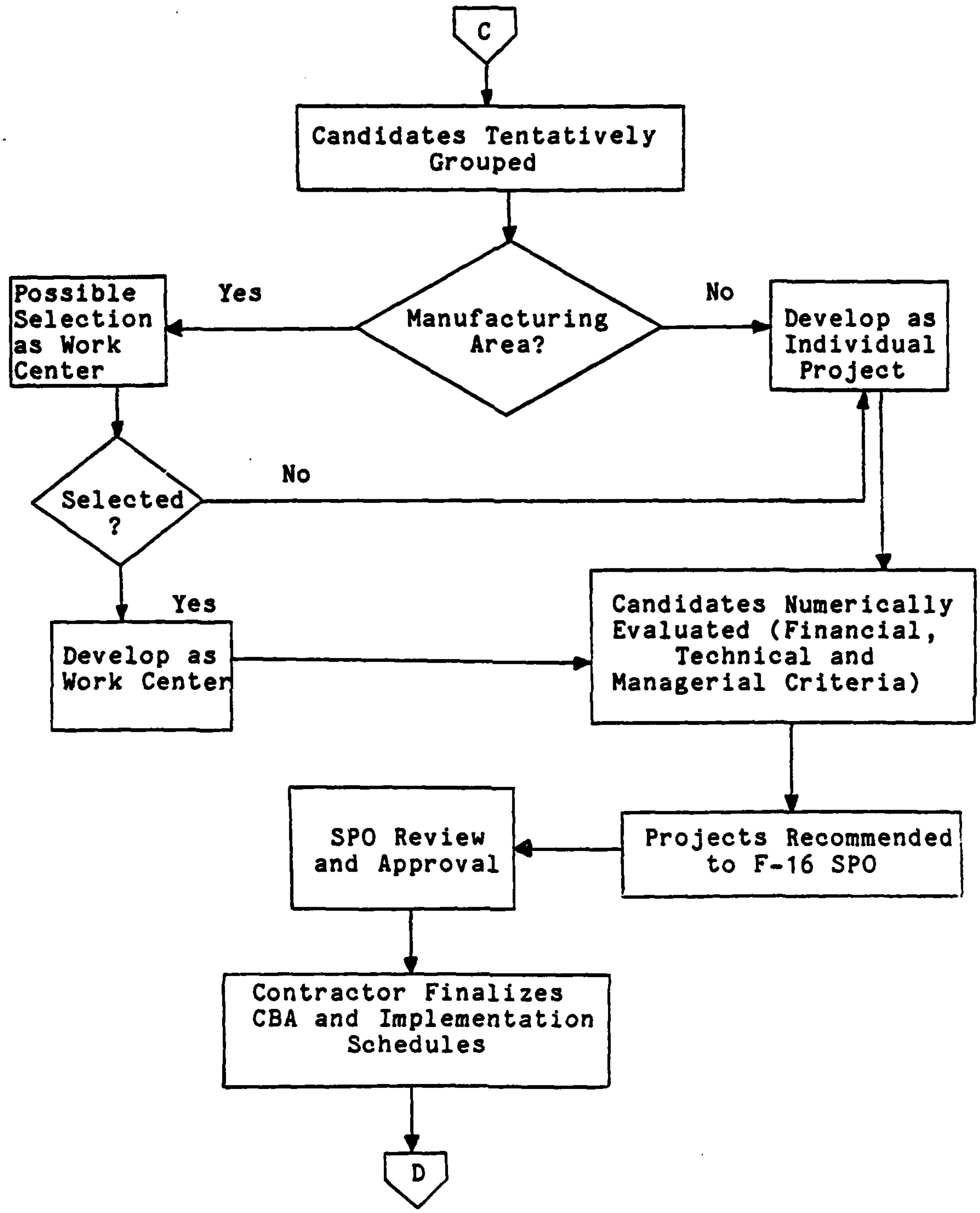


Figure 4.1(D). F-16 Tech Mod, Phase II

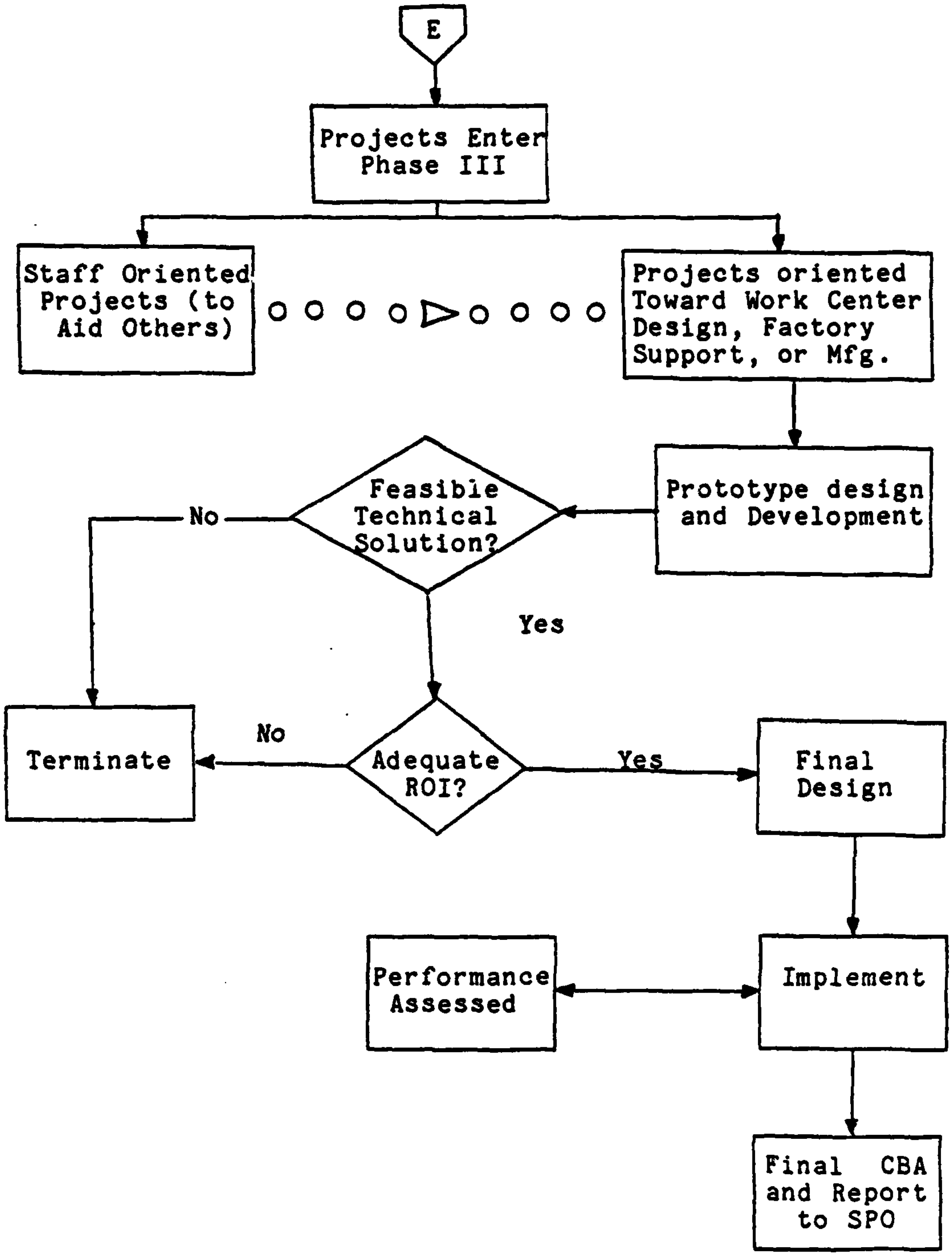


Figure 4.1(E). F-16 Tech Mod, Phase III

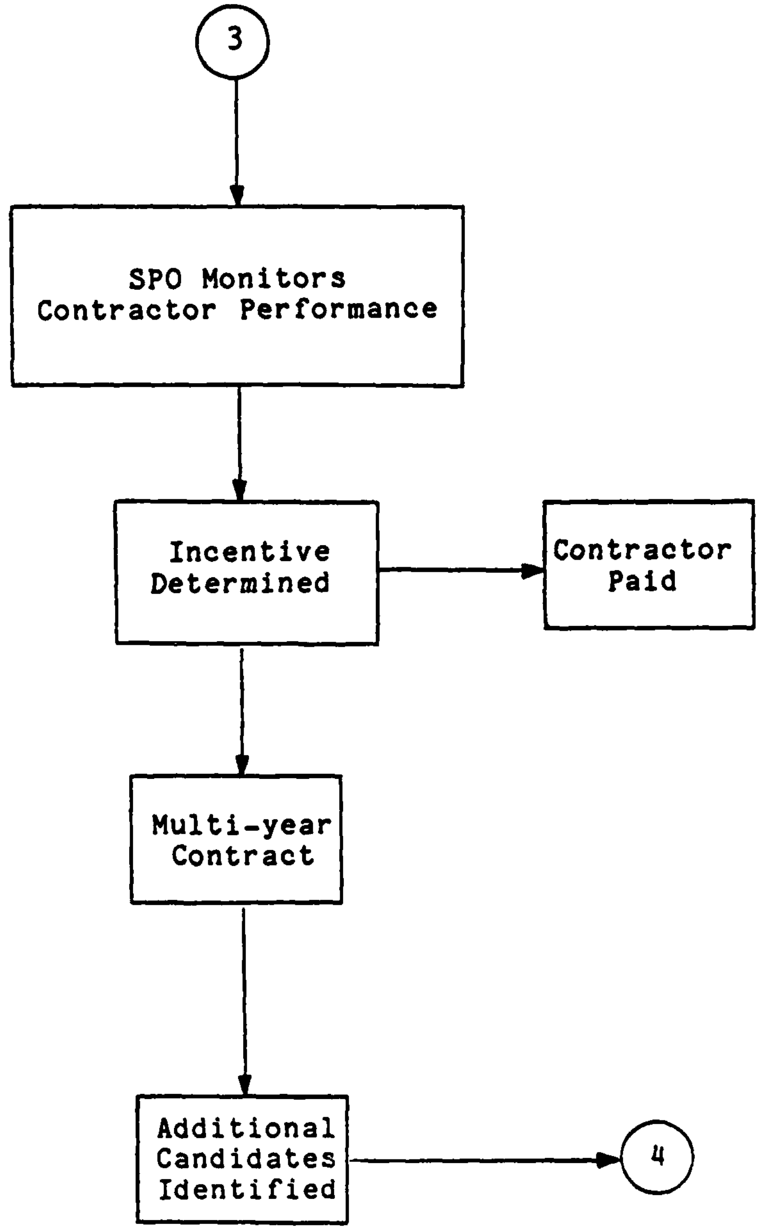


Figure 4.1(F). F-16 Tech Mod, Evaluation and Follow-up

was issued effectively prohibiting the Air Force from making the agreed upon capital investment.

The DoD policy shift came at an extremely inopportune time from the SPO viewpoint and threatened program objectives. The SPO wanted to accelerate procurement of the F-16, and at the same time they wanted a quality product at the lowest possible acquisition cost. USAF capital investments coupled with an aggressive investment strategy by the contractor would have enabled the Air Force to realize these goals and at the same time would have enhanced Plant No. 4's value as a national asset. But because of the new policy General Dynamics was in a tenuous position and faced a predicament which would confront all contractors. Namely, available incentives, financial and otherwise, were insufficient to motivate General Dynamics to assume all the risk and make capital investments of the magnitude required. General Dynamics had no guarantee that they would receive even reasonable returns on any modernization investments they made, and they realized that any modernization efforts initiated to improve their efficiency would not only reduce weapon system cost but would also decrease their profits. The bottom line was that unilateral modernization ventures by General Dynamics were prohibitively unattractive in light of numerous other investment opportunities available. The economics of the situation dictated that General Dynamics should not make the substantial capital investments needed

at Plant No. 4 unless some other arrangement could be worked out with the Air Force.

The controversial DoD policy change forced the Air Force to seek an alternative scheme to provide contractor incentives. Between 1975-1977, the USAF (F-16 SPO) initiated several brainstorming sessions in an attempt to discover an acceptable solution. The F-16 SPO, General Dynamics and the Air Force Wright Aeronautical Laboratories (AFWAL) were represented at these meetings; and each organization had a different perspective to be considered. For example, General Dynamics wanted to modernize but needed reasonable returns on any investments they would make. The F-16 SPO wanted to accelerate acquisition of the system at the lowest possible costs, and AFWAL was interested in advancing and enhancing state-of-the-art manufacturing techniques. The result of their collective desperation was an innovative program:

> . . . conceived to establish a manufacturing environment that would minimize the manufacturing costs of F-16 aircraft . . . through the application of new technology and a financially sound capital investment program [45:1].

The plan they outlined was the forerunner of the present Technology Modernization program.

Under the original Tech Mod contract, both the Air Force and General Dynamics made certain commitments designed to ensure eventual program success. The AF agreed to

provide $25M for manufacturing technology projects at General Dynamics and for funding Phases I and II of the multi-phased development effort with the stipulation that the F-16 SPO agree to reduce budget projections by at least $220M by FY86. This $220M represented expected savings attributable to the USAF and General Dynamics investments. For their part, General Dynamics agreed to invest up to $100M for capital acquisitions provided they received sufficient investment protection and adequate incentives. The required investment protection was approved by the Secretary of the Air Force and included provisions concerning depreciation payments associated with previously unforecasted facilities, investment tax credits (which actually required Congressional approval), cost of money, and termination protection (indemnification) (44:3).

Under the termination procedure, the government agreed to provide partial relief to General Dynamics if the total aircraft buy numbered less than 1158. This figure included units produced for the USAF, for the European Participating Group, and for Foreign Military Sales. Table 4.1 shows at what percentage of cost the government would have acquired the modernized facilities if the buy had fallen short of the 1158 figure. For example, if only 89 F-16s had been purchased the government would have acquired the facilities at 98% of cost.

TABLE 4.1

Government Acquisition Schedule Under Termination Agreement (5:53; 36:26)

Total Aircraft Procured	Percent of Undepreciated Capitalized Acquisition Cost
1 - 90	98
91 - 310	95
311 - 592	90
593 - 893	85
894 - 1158	80

Besides the protection granted by the government on General Dynamics' capital investments, the contractor received certain other incentives outside the purview of the base contract. These modernization incentives were necessary because, as shown in Figure 4.2, depreciation allowances and the profit on depreciation and cost of money alone would not have allowed the contractor to recoup his initial investment much less realize a profit. Specifically, there were performance incentives added to the contract as well as award fee provisions which were contingent upon General Dynamics' management of the F-16 Tech Mod program for the Air Force. Performance incentive payments were to be based on General Dynamics capital investments and were tied to three actions (45:9):

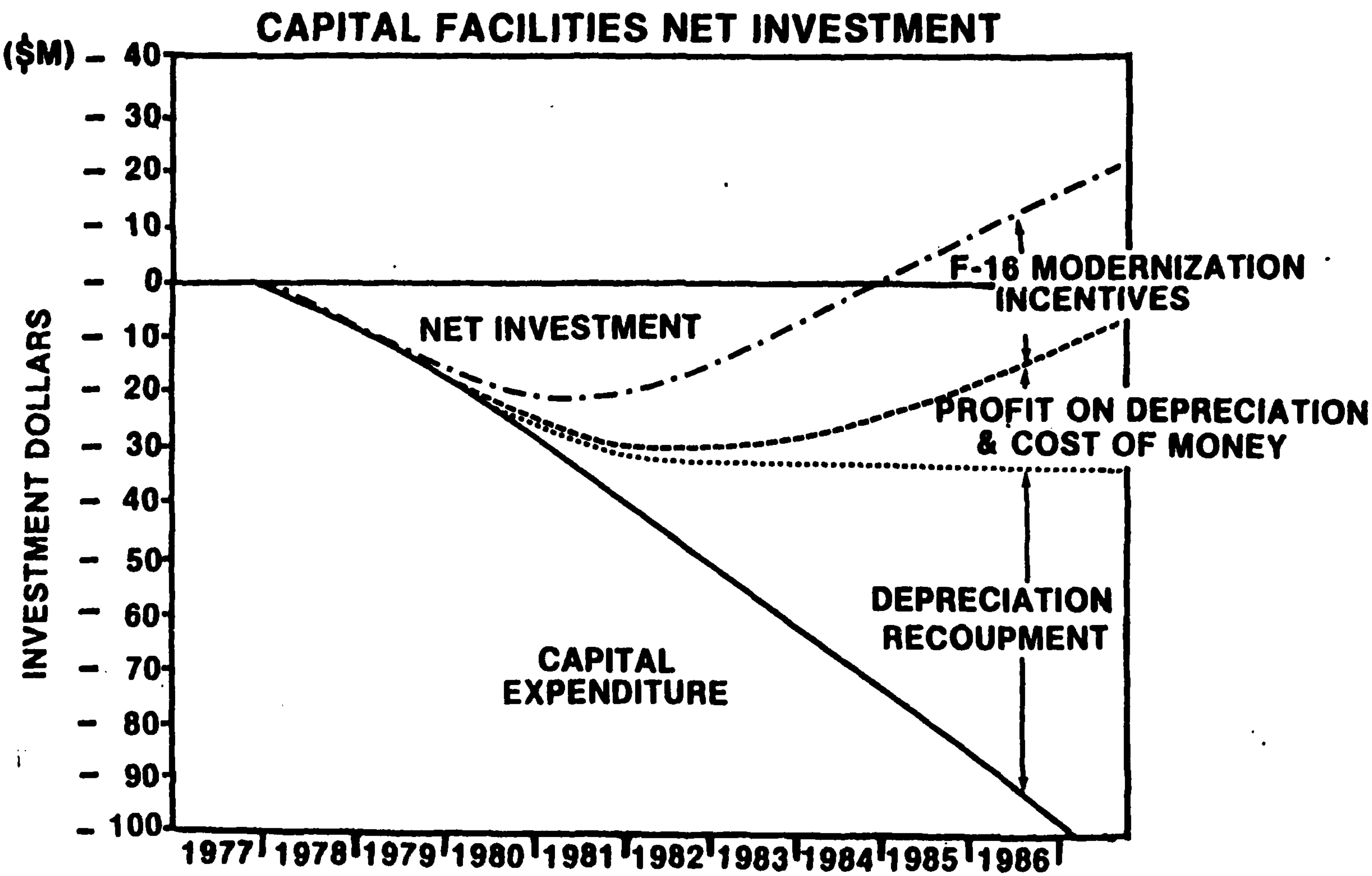


Figure 4.2. Capital Facilities Net Investment (Plant Modernization Fort Worth Division) (45:28)

1. procurement of facilities to an agreed-upon schedule,

2. implementation of technology developments according to the contract schedule, and

3. validation of direct labor savings achieved on the production program.

A $1M annual award fee was used to insure the consistency of General Dynamics program objectives with those of the Air Force.

The First Air Force Tech Mod

Armed with the Tech Mod contract and Air Force seed funding, General Dynamics established a dedicated program office to administer the Tech Mod program (see Figure 4.1(B)). The role of the program office was "providing support for development of sufficient incentives and contractual provisions mutually beneficial to both the USAF and General Dynamics [45:3]." To this end, USAF and General Dynamics negotiators had agreed that the Technology Modernization of Air Force Plant No. 4 would be accomplished in phases, and the "three-phase technology development effort was begun in September 1978 [45:2]." Phase I (see Figure 4.1(C)) ran from Nov 78 to Apr 79 and included a factory analysis plus the identification of candidate Tech Mod concepts. Initially it was necessary for General Dynamics to analyze plant operations and identify system cost drivers by establishing baseline manufacturing costs

for the F-16 which allowed identification of modernization opportunities. Then an exhaustive "top-down" factory analysis pinpointed specific concepts as modernization candidates. The concepts were screened based on criteria which evaluated their overall cost-effectiveness in terms of minimizing technical risk, minimizing disruption of manufacturing operations, and maximizing economic benefits. The Tech Mod technique was innovative but unproven, and it was important (at least initially) to choose candidates with high probabilities of immediate success to demonstrate that the program could work. Accordingly, candidate concepts which did not meet minimum criteria were eliminated from further consideration while acceptable concepts were closely scrutinized to develop cost-benefit analyses (CBA), capital investment strategies, and financial and technical baselines. Approximately eighty candidate concepts "survived" to Phase II.

During Phase II (see Figure 4.1(D)) of the F-16 Tech Mod, which took place between April and November 1979, complete economic and technical evaluation of possible concepts was accomplished by General Dynamics. Concepts were tentatively grouped into cells and work centers; and then all candidate enabling technology programs were numerically evaluated using financial, technical, and managerial criteria. From this procedure, a prioritized list of potential projects was given to the F-16 SPO as

reccommended development programs (33 in the original effort). SPO review of the General Dynamics recommended projects was primarily a subjective consideration of such things as risk, cost, and contractor capital commitment; and the 33 projects were all approved for continuation in the Tech Mod program. Once General Dynamics finalized their cost-benefit analyses and implementation schedules, the 33 projects entered the third and final phase of Tech Mod.

Phase III of the F-16 Tech Mod (see Figure 4.1(E)) began in November 1979. During the course of this phase "successful projects were brought to implementation as a result of frequent cost-benefit analyses and detail engineering design developments [45:3]." Two categories of projects entered Phase III--those which were staff oriented and expected to contribute to other Tech Mod projects at General Dynamics and those which were oriented toward work center design, factory support, and manufacturing activities. Prototypes were developed for those projects related to actual factory operations. If General Dynamics determined that there was no feasible technical solution to a problem or that a project could not achieve an acceptable ROI for the contractor, the project was terminated (6 of the original 33 were terminated). Projects which continued through the Tech Mod process went into final design and then implementation. Once projects were implemented, General

Dynamics conducted performance assessments and presented their findings to the SPO as part of the final CBA.

It was through progress reports that the Manufacturing Directorate of the F-16 SPO was able to monitor the progress of the contractor, and based on General Dynamics' reported performance, incentives were paid (see Figure 4.1(F)). Additionally, based on the success of Tech Mod, the program with General Dynamics has been extended in the F-16 multi-year agreement. Projects continue to be identified and progress through the process, as described above (and as depicted in Figure 4.1, parts (C), (D), (E), and (F)). General Dynamics, as managers of the F-16 Tech Mod for the SPO, continues to identify projects which have the potential to save program dollars. The SPO's Manufacturing Directorate, acting on information provided by the contractor, makes the "go, no-go" decision and the cycle begins anew.

The success of the F-16 Tech Mod can be assessed in terms of program accomplishments from its inception in 1978 to the present (44:21; 45:29). The list of accomplishments is long, and the program has impacted not only the F-16 but a good portion of the aerospace industry as well. Implications for industry in general include establishment of a standard methodology for increasing factory productivity, and for increasing industrial preparedness. Additionally, the program has demonstrated technology

advancement in the tool industry and is accelerating technology toward the "factory of the future." The more immediate benefits of the program have been realized by the F-16 SPO and General Dynamics. Specifically, the F-16 program target cost has been reduced by $64M, and several hundred million dollars in additional savings are expected to be generated depending on the length of the production run. Contractor performance to schedule has been outstanding, production quality has improved, and new technology has been introduced into the production process without disrupting work flow. In 1979, the eleventh F-16 produced took 110,000 man-hours to manufacture. By contrast, and largely due to the success of the F-16 Tech Mod, the 437th F-16 required only 29,000 man-hours to manufacture in 1983 (44:20). One final benefit which holds much promise has been the initiation of a modernization program with General Dynamics subcontractors.

Industrial Technology Modernization

Benefits generated by the in-house Tech Mod between General Dynamics and the USAF are being extended to General Dynamics subcontractors through a program called Industrial Technology Modernization (ITM). Rationale for this action is simple--subcontractors account for 65% of total F-16 costs, and savings generated through modernization of General Dynamics subcontractors could result in substantial program savings. General Dynamics administers the ITM

program for the Air Force, and Figure 4.3 presents the process by which subcontractors are selected to participate. The process begins when General Dynamics subcontractors receive a program orientation and are given goals and planning packages from which they can develop modernization proposals. Subcontractor proposals are reviewed and prioritized by General Dynamics, who then makes recommendations to the SPO based on their evaluation. The SPO reviews General Dynamics recommendations, and based on criteria which includes degree of (subcontractor) management commitment, and availability of funds, the SPO decides which subcontractors they want to include in the ITM program. Selections generally parallel General Dynamics recommendations, and the availability of SPO manpower (to monitor and manage the programs) and seed funds for the development efforts determine when Tech Mod contracts will be awarded. These two factors (SPO manpower and seed funding) are the only current limitations on the size of the ITM program.

The ITM program has objectives similar to those of the in-house program with General Dynamics. Program goals are to reduce system cost, improve quality, increase capacity, and enhance reliability. In pursuit of these goals, General Dynamics and the USAF plan to reach up to 61 subcontractors by 1993. The program will affect more than just the F-16. In fact, it includes some subcontractors involved in work on

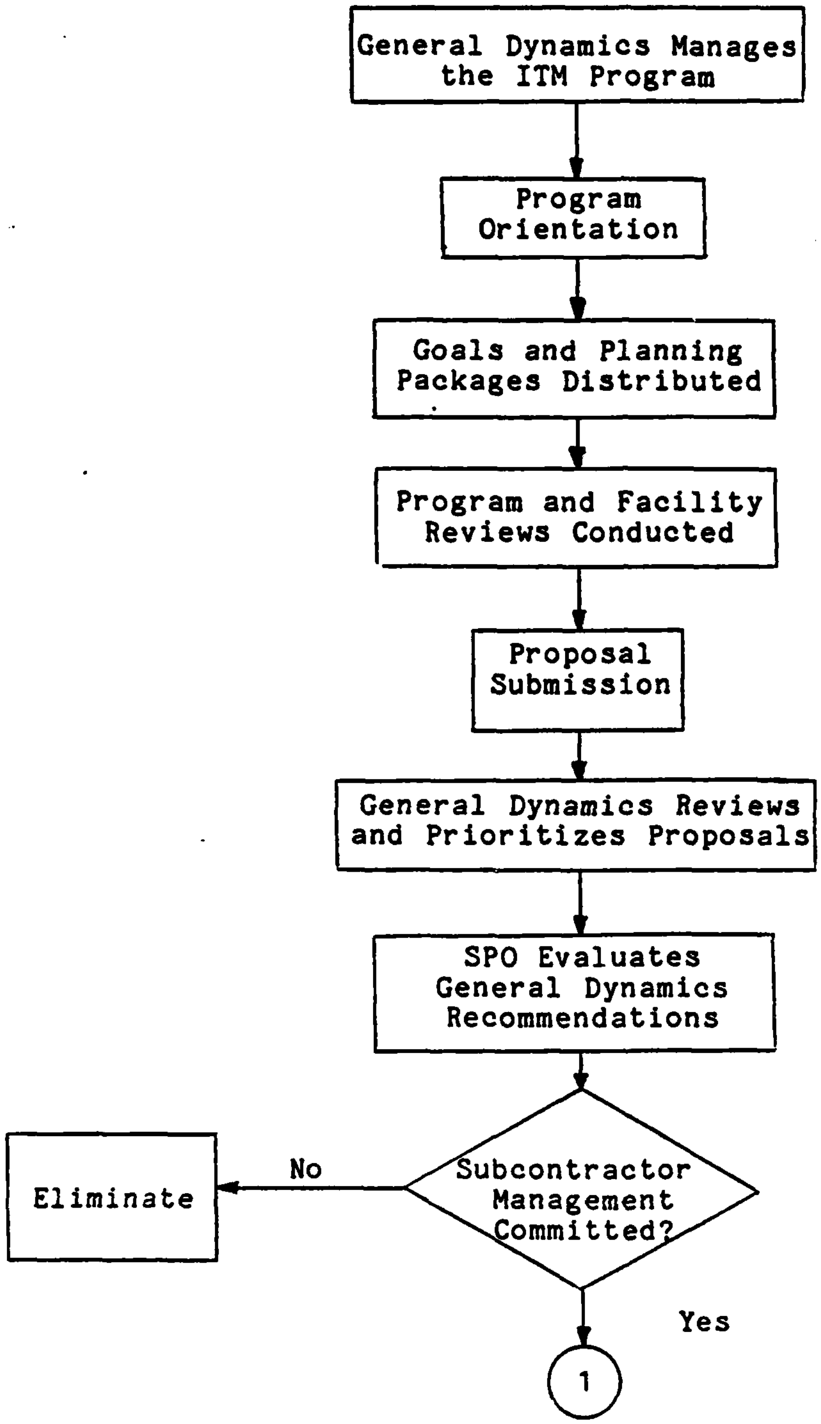


Figure 4.3. Industrial Tech Mod Program Decision Process

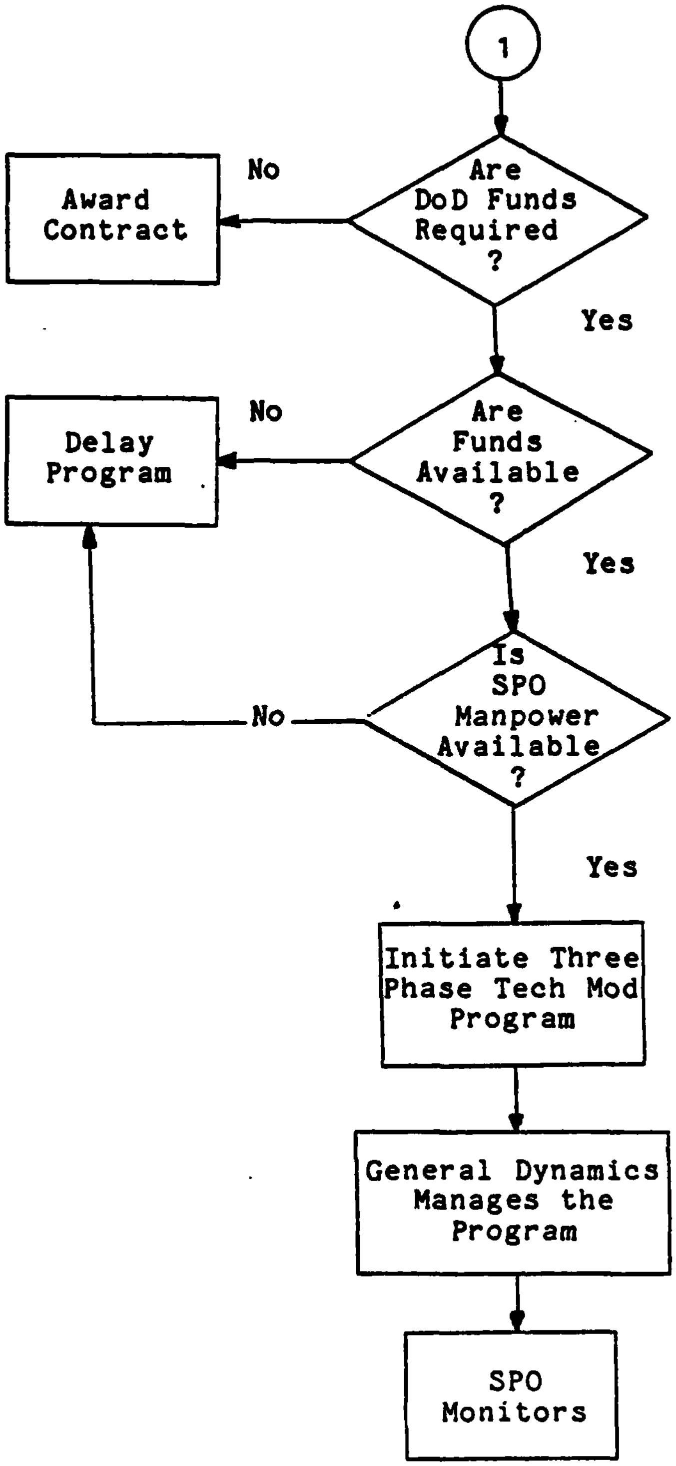


Figure 4.3. Industrial Tech Mod Program Decision Process (Continued)

other DoD programs (the B-1, for instance). At present, 15 subcontractors are producing impressive results. They have committed to making capital investments totalling over \$173M. The estimated DoD-wide savings from these programs are expected to be in excess of \$450M. The entire ITM venture is well on its way to success, and projected savings of \$1B-plus through 1993 attest to this assertion.

The B-1B Tech Mod: An Alternative View of the Vertical Approach

Whereas the F-16 Tech Mod program represents one perspective of the vertical approach to Technology Modernization, the B-1B provides an alternative view of the same general approach. Figure 4.4 depicts the development of the B-1B Tech Mod program and represents decisions involved at inception of the program through selection of individual Tech Mod projects at contractor plants.

ASD policy makes Tech Mod a mandatory consideration for all major acquisition programs, and a feasibility assessment showed that such a venture could prove beneficial for the B-1B acquisition program. Accordingly, the SPO developed three major objectives to be realized through Tech Mod (4:1):

1. reduction of B-1B production costs,

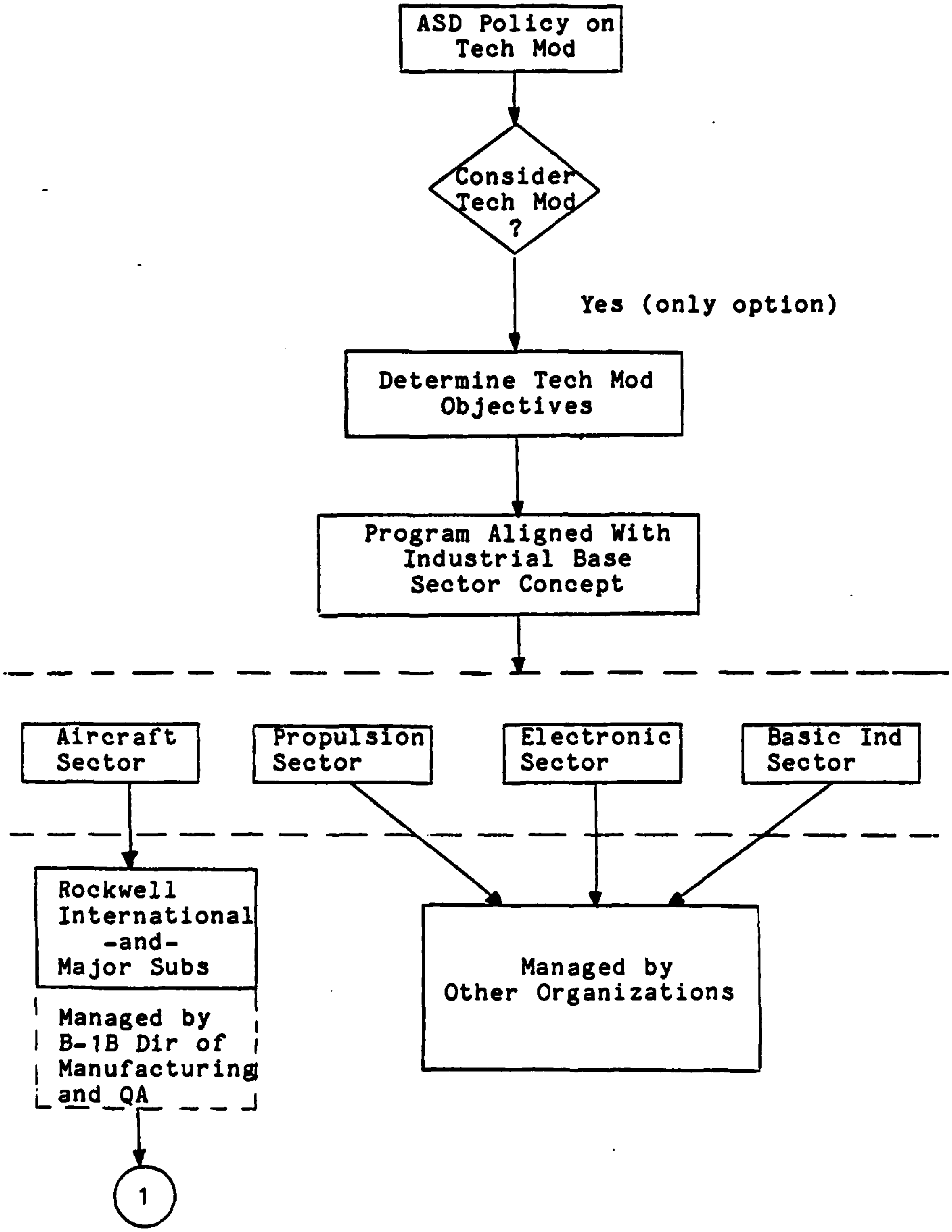


Figure 4.4. B-1B Tech Mod Decision Process

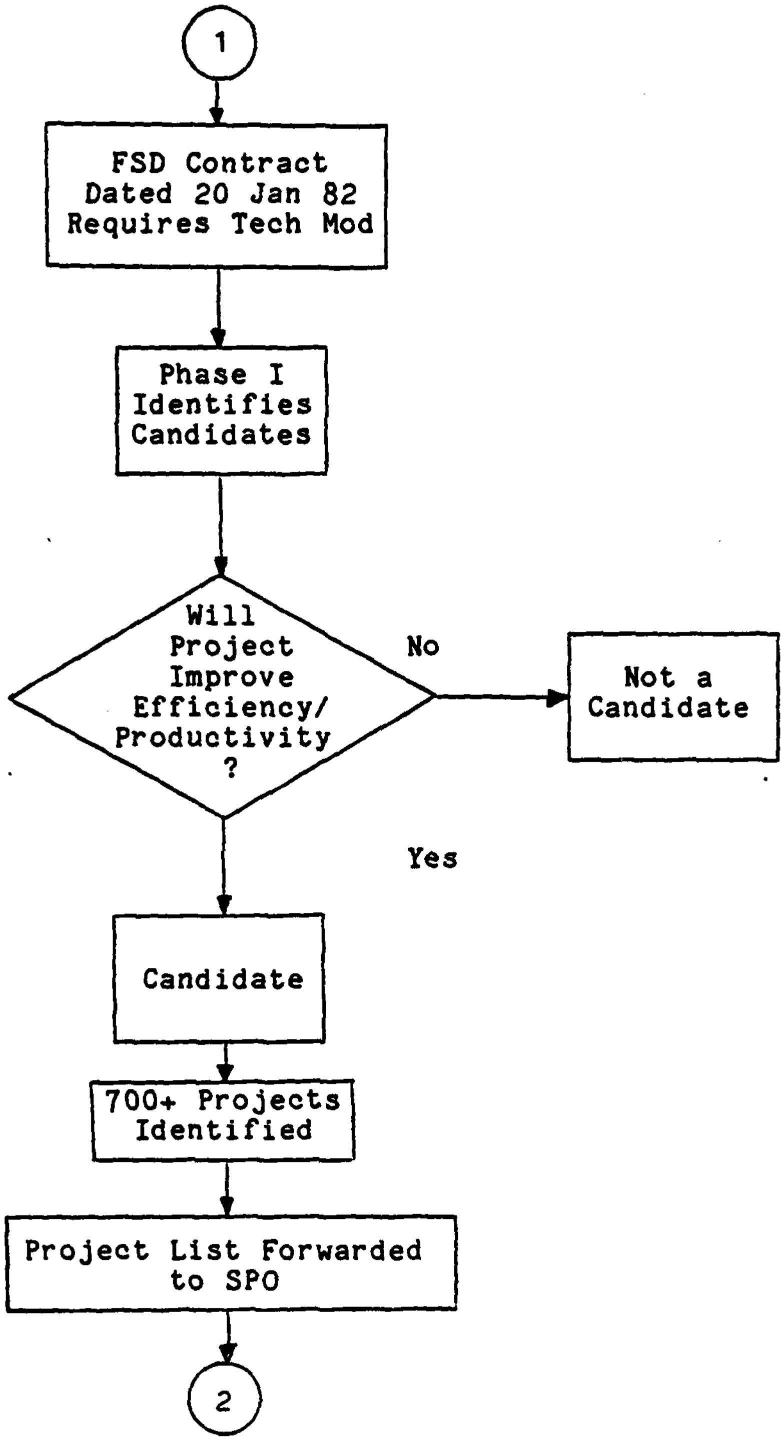


Figure 4.4. B-1B Tech Mod Decision Process (Continued)

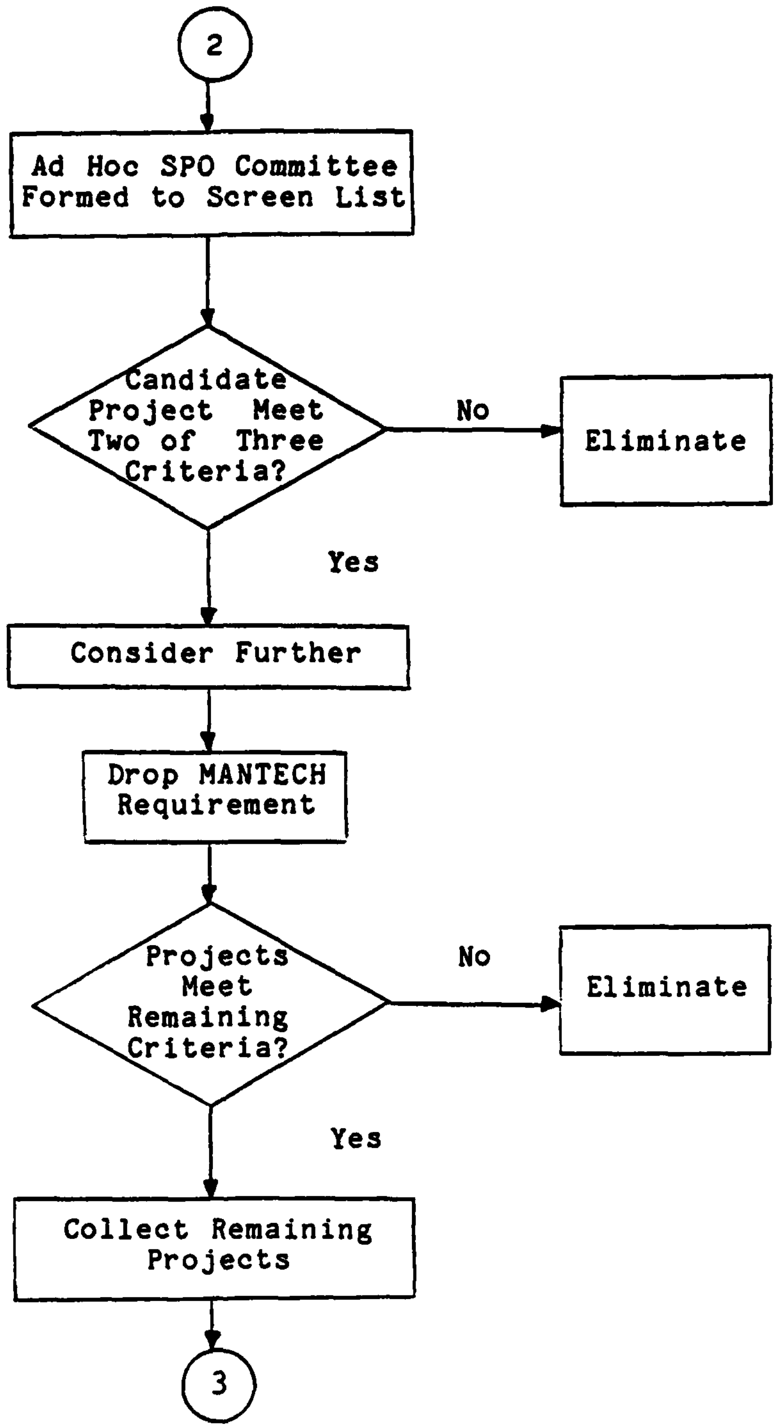


Figure 4.4. B-1B Tech Mod Decision Process (Continued)

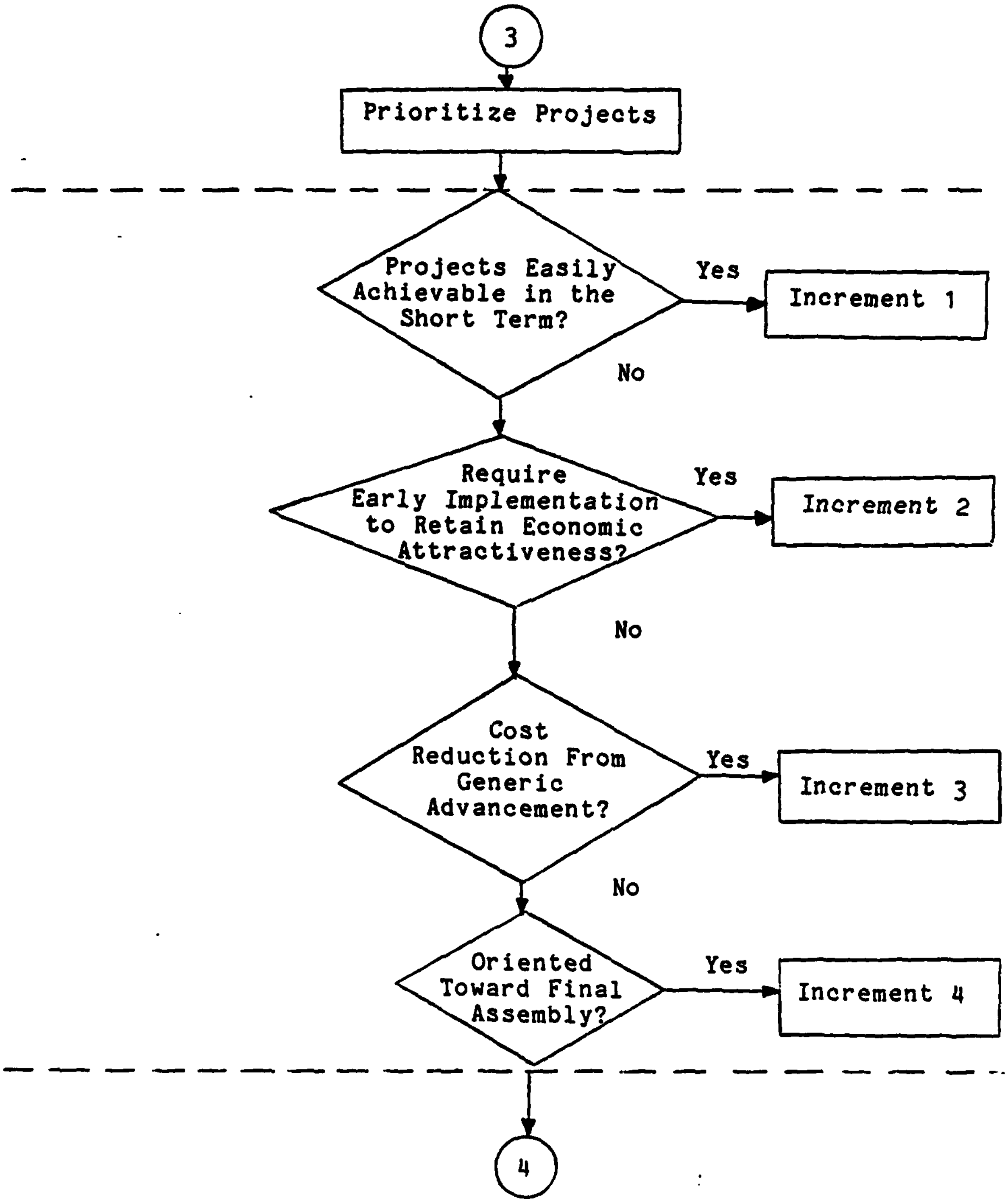


Figure 4.4. B-1B Tech Mod Decision Process (Continued)

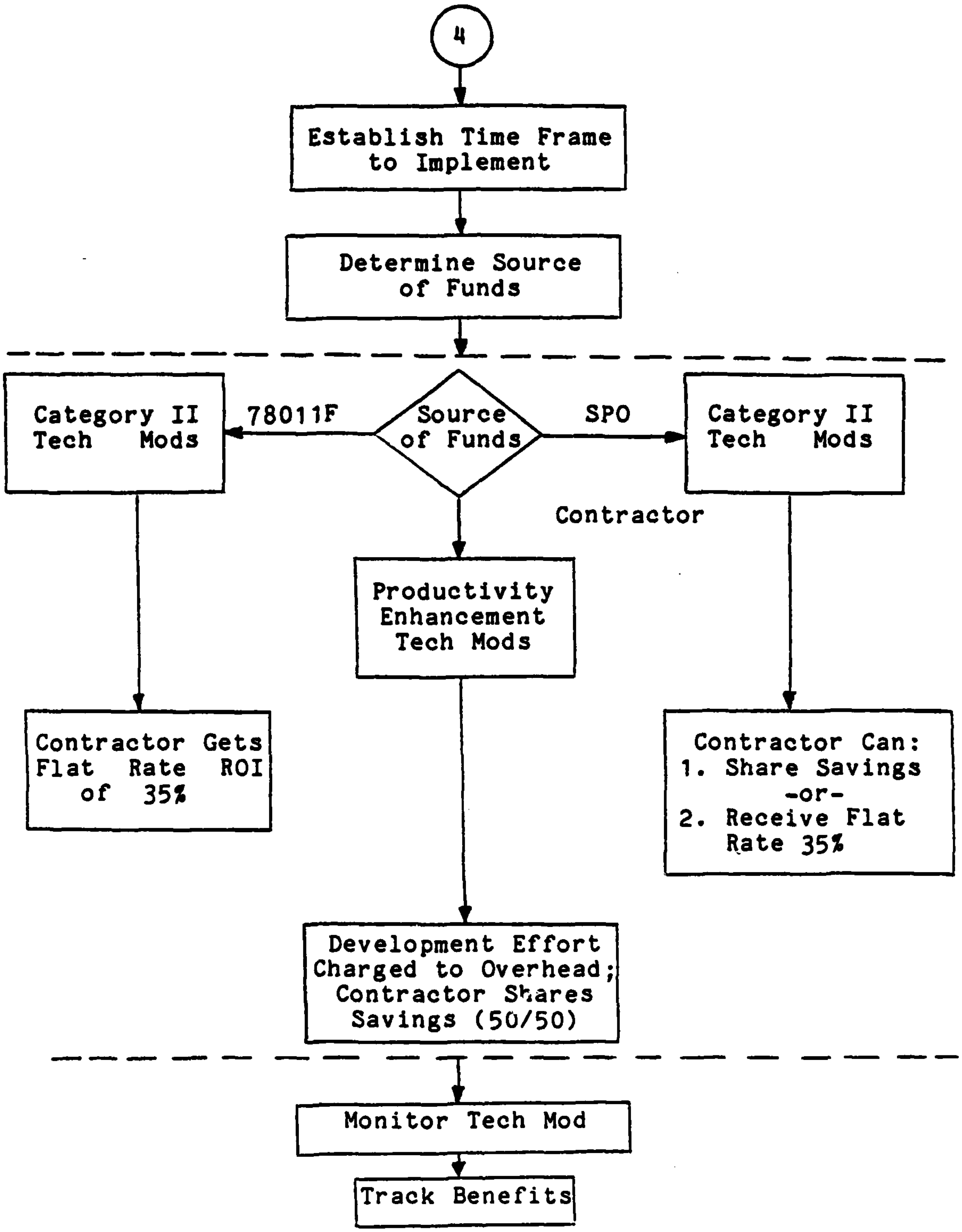


Figure 4.4. B-1B Tech Mod Decision Process (Continued)

2. enhancement of B-1B quality and reliability, and

3. contribution to defense industrial base modernization.

The program was to be structured to take advantage of manufacturing technology (MANTECH) advancements and was aligned to coincide with the AFWAL Industrial Base Sector Concept. However, while the AFWAL concept divides the aerospace industrial base into eight sectors, the B-1B focus would be concentrated on the following four (4:1):

1. the Aircraft Sector,

2. the Propulsion Sector,

3. the Electronics Sector, and

4. the Basic Industries (or Production Base) Sector.

Furthermore, only the Tech Mod effort in the Aircraft Sector was to be managed by the B-1B SPO. The Tech Mods in the Propulsion Sector and Electronics Sector were to be administered by ASD's Deputy for Propulsion and ASD's Deputy for Airlift and Trainers respectively, and the ASD Centralized Tech Mod Management Office would manage the program involving the Basic Industries Sector.

When the Air Force and Rockwell International signed $2.2B in Full Scale Development (FSD) and Production contracts in January 1982, the FSD contract contained a requirement that the contractor conduct the Phase I factory

analysis (31). This action initiated the B-1B Tech Mod. From the preliminary analysis, Rockwell identified over 700 candidate projects (for Rockwell and its major subcontractors) with some potential to improve program efficiency and productivity. The list of candidate projects was forwarded to the B-1B SPO for review and determination.

The SPO established an ad hoc committee to select contractor-identified projects which would eventually be incorporated into the B-1B Tech Mod program. The committee mandate was to decide which projects would contribute to the SPO priority of a quality aircraft. The committee ranked (or prioritized) projects on the basis of three criteria (31):

1. whether or not the project involved a MANTECH thrust area,
2. whether or not the project was achievable for the B-1B, and
3. whether or not project implementation would save program dollars.

This constituted a subjective evaluation.

The B-1B Tech Mod was designed to be a cost <u>reduction</u> program, as opposed to a cost <u>avoidance</u> program (like the original F-16 Tech Mod program had been). That is, because of the short (5 year) scheduled production run, the B-1B SPO was interested in Tech Mod projects which would provide savings on the instant contract as well as enhance system quality. Accordingly, only projects that could be

implemented in an acceptable time frame would be considered because of their potential to insure the B-1B program did not exceed the $20.5B ceiling established by Congress.

Of the original 700-plus projects submitted by Rockwell approximately 130 satisfied two of the three SPO criteria and were subsequently "passed" for further consideration. To narrow the list even further, the criterion concerning MANTECH thrust areas was eliminated since Tech Mod is not strictly limited to consideration of new technologies, and the remaining 130 projects were re-evaluated (4:5). Ninety projects (approximately) met both remaining criteria. These projects were selected by the SPO committee for inclusion in the B-1B Tech Mod program.

The next step in the process was for the SPO to prioritize projects for implementation. This was done using expected financial return and time criticality as criteria. The prioritization of projects was decidedly subjective, and resulted in a categorization scheme which contained four implementation increments. Increment 1 comprised those projects (5 in number) which were classified as immediate opportunity targets. Essentially, these projects were chosen for early implementation because they were likely to provide a quick ($) return thereby establishing the B-1B Tech Mod as a successful program. There were approximately 20 projects in the second increment, and these projects required early implementation to retain their economic

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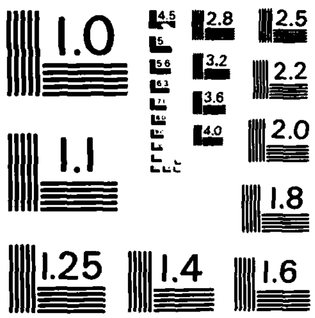

MICROCOPY RESOLUTION TEST CHART
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attractiveness. Third increment projects were those which emphasized cost reduction from generic technology advancements. There were approximately 50 projects in this category. It was felt that these 50 could be brought on line in mid program without disrupting production. The fourth and final implementation increment included all remaining projects (roughly 15 total), and they were oriented toward final production of the aircraft. (31)

Once the four increments had been defined, it became necessary to develop a time frame for actual implementation. Once again the relatively short production run was a factor to be considered, and the B-1B SPO decided that all projects had to be underway by production of aircraft 50 of a planned 100 unit production run (31). Funding of the various development projects would come from one of three sources and would determine how the incentives would be provided to the contractor. The three sources of program funds were to be (31):

1. SPO program reserves,
2. Industrial Preparedness Funds (PE78011F), or
3. contractor dollars.

Projects funded from SPO program reserves would be classified as Category I Tech Mods and would involve large capital commitments by the contractor(s). For these projects, the contractor would either share the resultant

(verified) savings on a 50/50 split at the end of production, or would submit a voucher and receive a pre-negotiated flat rate ROI of 35% instantly. Projects funded from PE78011F were to be designated Category II Tech Mods, and could be thought of as the "classic" Tech Mods. Under this arrangement, the contractor would receive a flat-rate ROI of 35%. The final funding option available is the case where the contractor funds the entire project. These type projects would be identified as Productivity Enhancement Tech Mods by the SPO, and the contractor would charge the development effort to overhead and shares savings (50/50) at the end of production. (31)

Unlike the F-16 Tech Mod where the contractor administers the program, the B-1B program is managed by the SPO Directorate of Manufacturing and Quality Assurance (ASD/B1D). That office monitors program progress and tracks all accrued benefits. The program is set up such that guidance and direction are provided by an Executive Steering Group and a B-1B Directors Steering Committee. These two bodies retain the power and authority to redirect the program as necessary. At present, the B-1B Tech Mod is "on target" with projected savings between $400-$600M. In addition to these substantial cost savings, the Tech Mod is expected to produce substantial improvements in system quality, enhanced reliability, decreased production flow time, and benefits for other DoD programs (4:26).

Horizontal Tech Mods: The CTM Office Approach

The two previous Tech Mod case analyses for the F-16 and B-1B Programs presented what is commonly referred to as the vertical approach to Technology Modernization. Vertical Tech Mods do generate some fall-out benefits which are felt DoD and industry-wide, but their main emphasis and primary impact is specific to the major system program with which they are associated. This is understandable, but does not necessarily serve the best interests of the Air Force. Ideally, Tech Mods should be targeted at the aerospace industry in such a way that the Air Force and DoD realize the greatest possible benefits. That is the essence of the horizontal approach to Tech Mod which was developed as a result of the success of the vertical approach of the F-16 Tech Mod but which attempts to achieve a more broad-based application of the technique.

The Centralized Tech Mod Management (CTM) office was created as an independent organization within ASD (see Figure 4.5) to provide a focal point for all Tech Mod efforts and to serve as administrators of PE78011F funds. While they are primarily oriented toward horizontal Tech Mods, the CTM office is not strictly limited to these broad-based efforts. In fact, the CTM charter established the office to manage (2:32):

1. programs involving prime contractors who supply many systems,

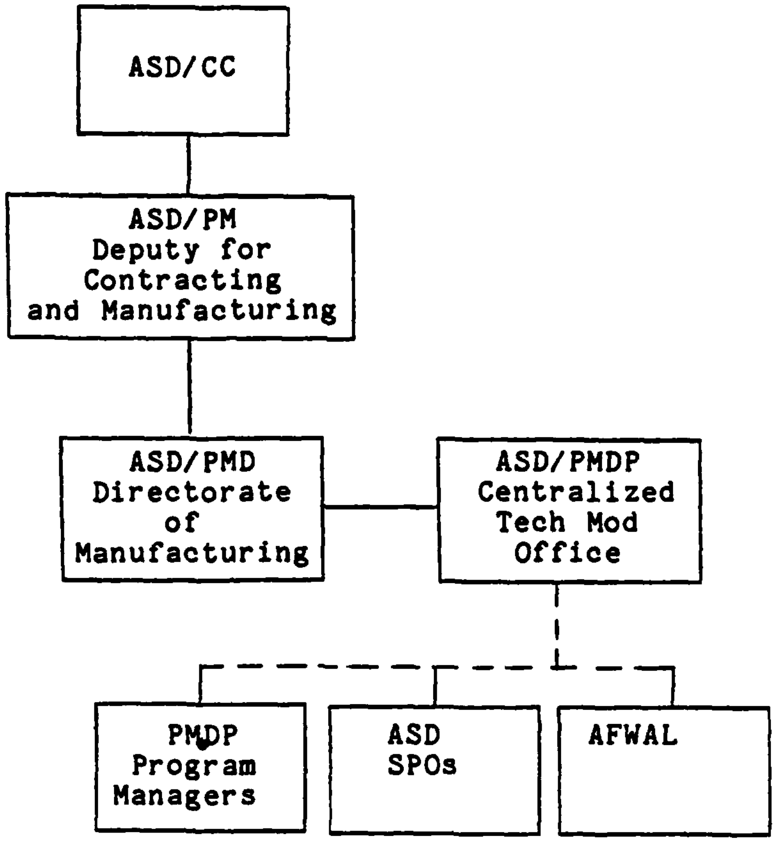

Figure 4.5. Centralized Tech Mod Office Hierarchy

2. programs with subcontractors, where the subcontractors have a diverse business base and supply several systems,

3. programs with subcontractors, when the subcontractors can deal more effectively with the government than through a prime contractor, and

4. programs involving entire industrial sectors.

Figure 4.6 traces the application of the Tech Mod concept, as applied by the CTM office to an entire industrial sector (i.e., horizontally). This representation (Figure 4.6) is a general analysis of the CTM office decision process. No specific programs or cases were studied due to limited accessibility and because of the sensitivity of proprietary data and the specter of ongoing negotiations. However, the view of the horizontal process as depicted herein is representative of the actual process followed and was developed through interviews and consultations with CTM office personnel.

The aerospace industrial base is divided into eight major sectors or thrust areas, and the goals and objectives have been established for each of these principal sectors. Each year, the CTM office completes a Production Base Analysis (PBA) which identifies industrial base needs and opportunities for cost reduction on major programs (2:26). PBA findings and recommendations lead to development of a Tech Mod investment strategy. The CTM office review of the PBA pinpoints industries where technology modernization

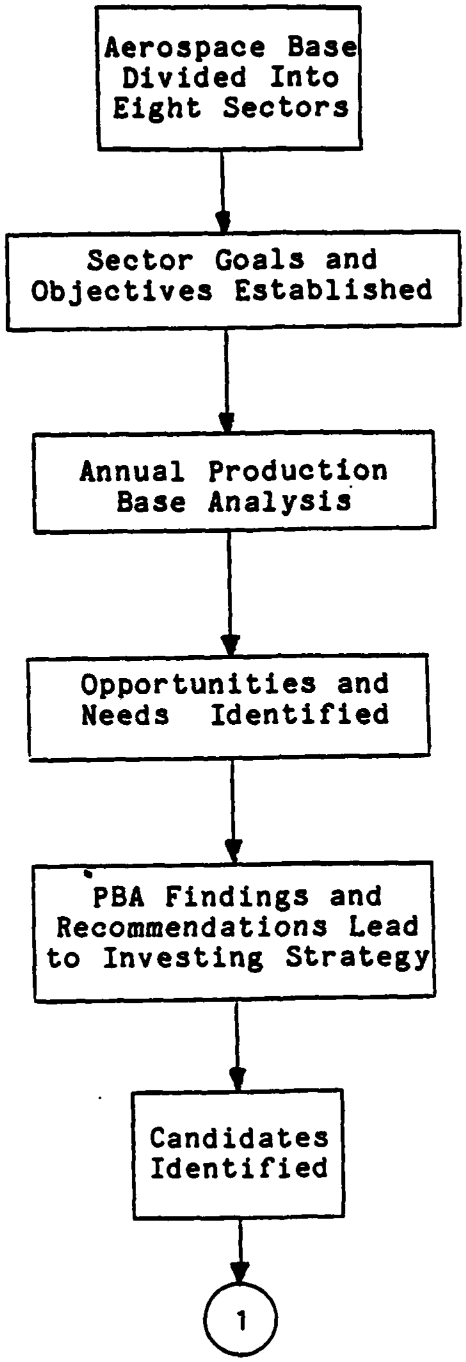

Figure 4.6. Centralized Tech Mod Office Decision Process

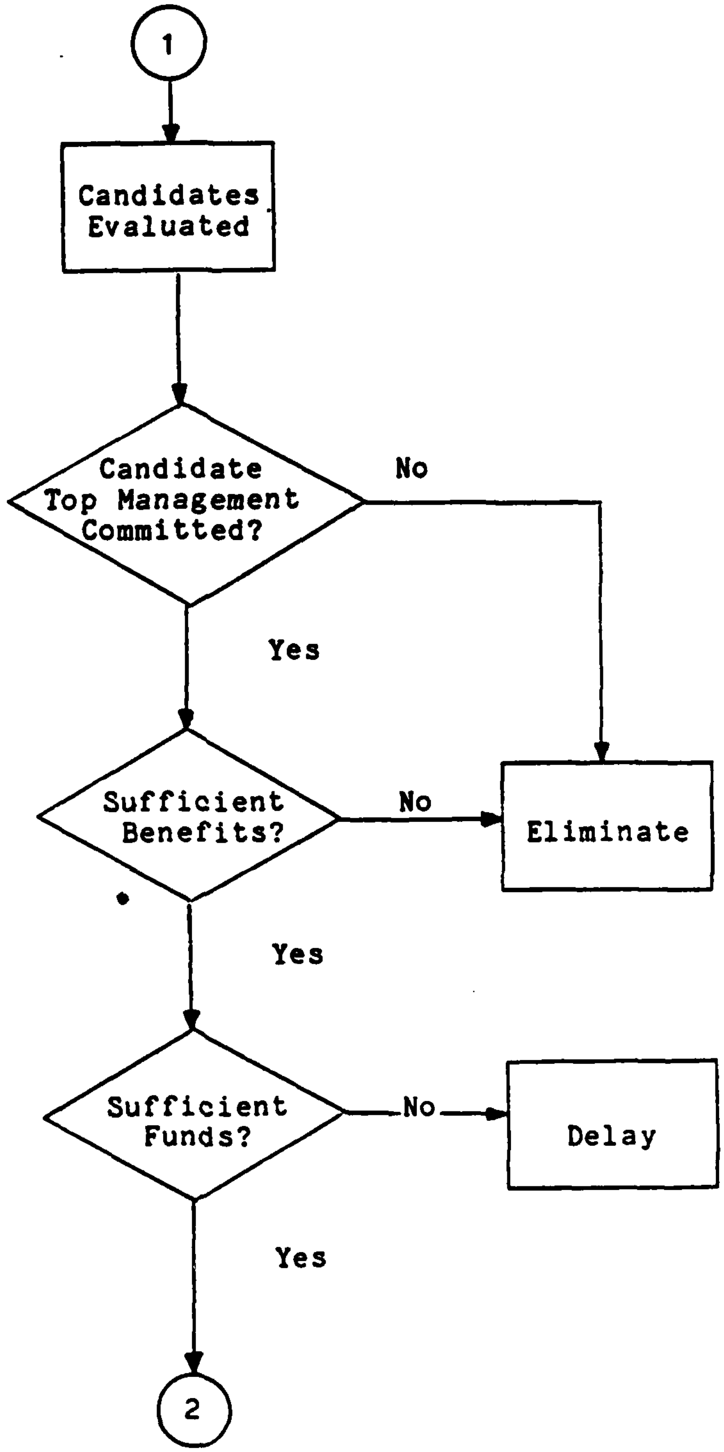

Figure 4.6. Centralized Tech Mod Office Decision Process (Continued)

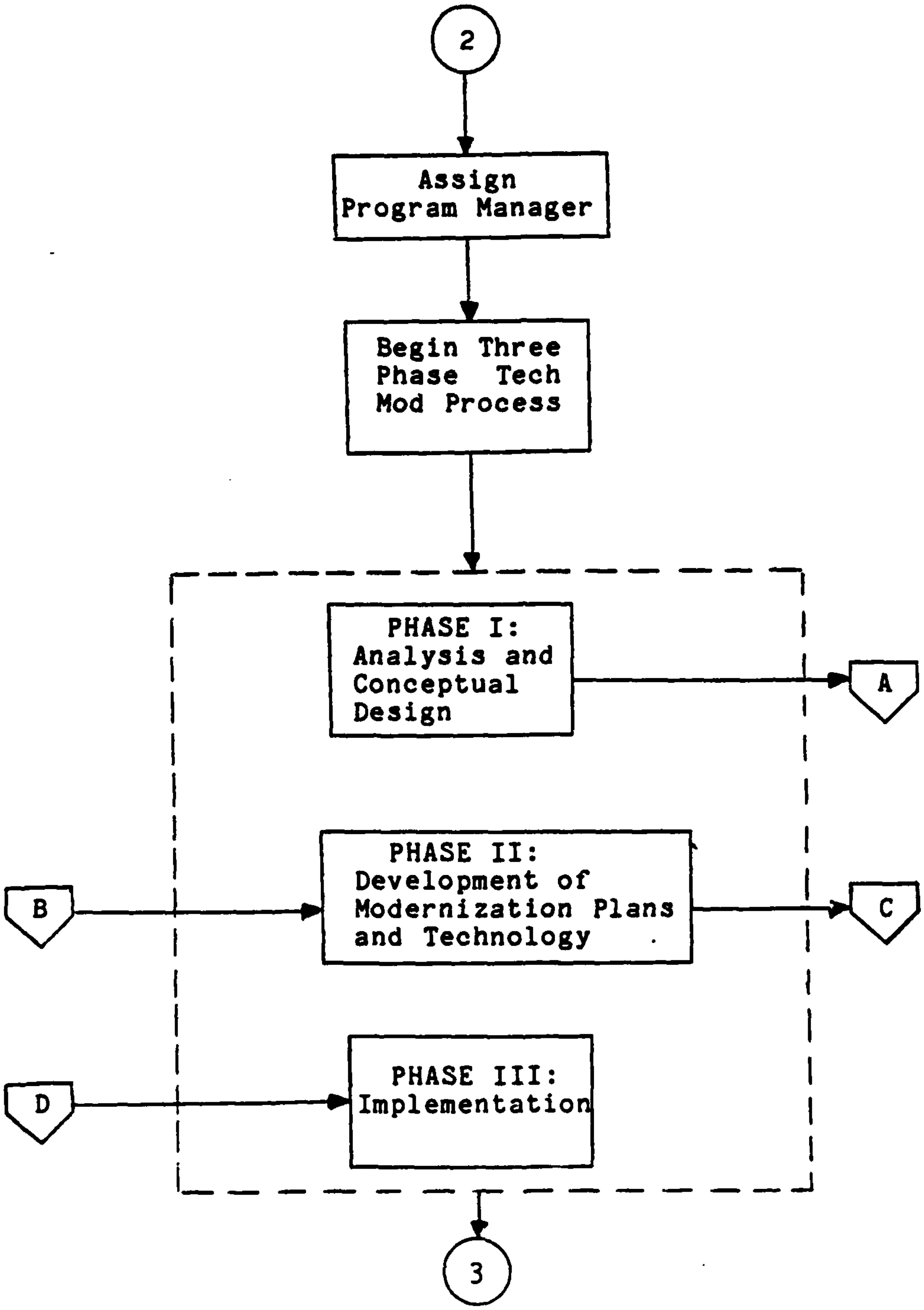

Figure 4.6. Centralized Tech Mod Office Decision Process (Continued)

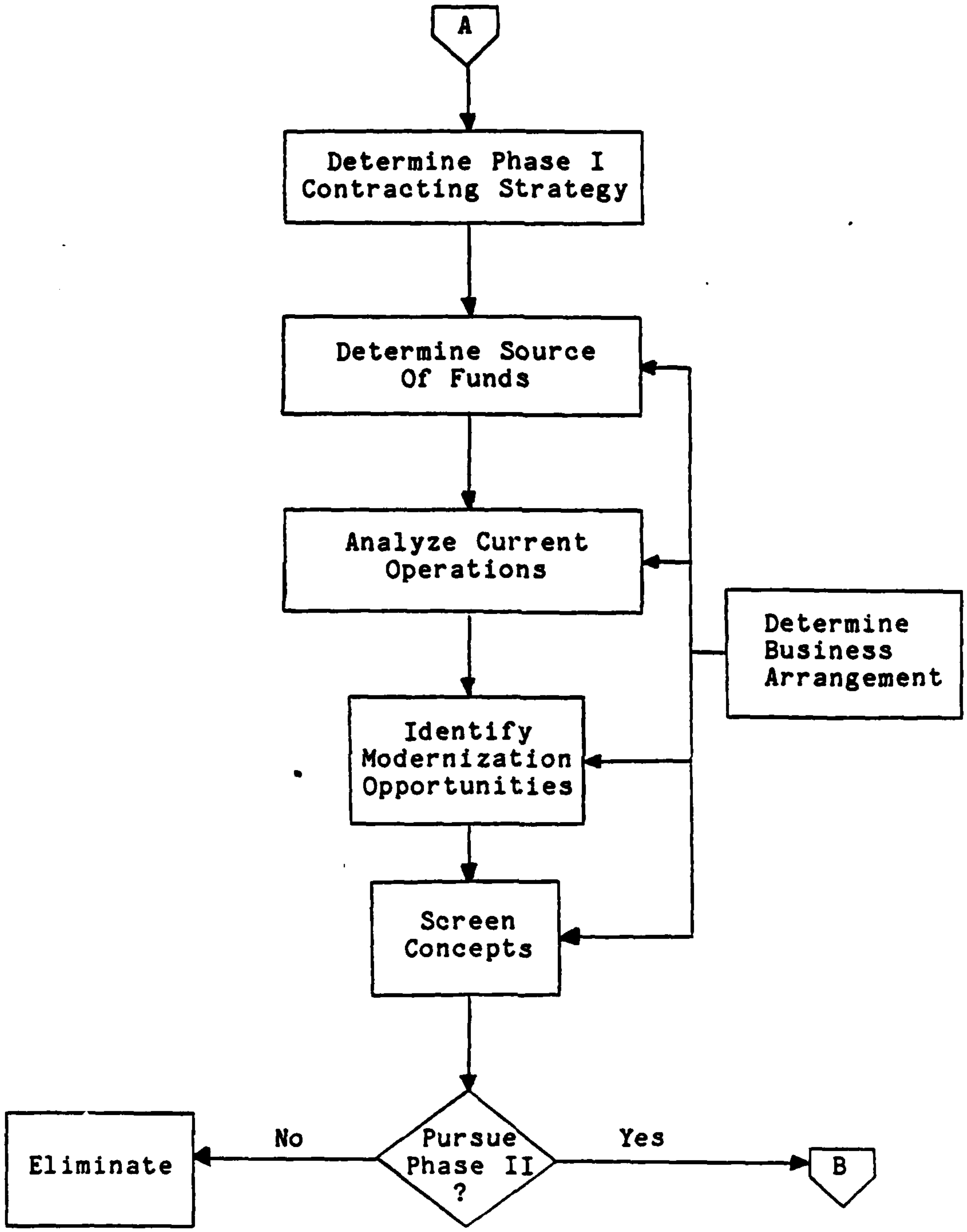

Figure 4.6. Centralized Tech Mod Office Decision Process (Continued)

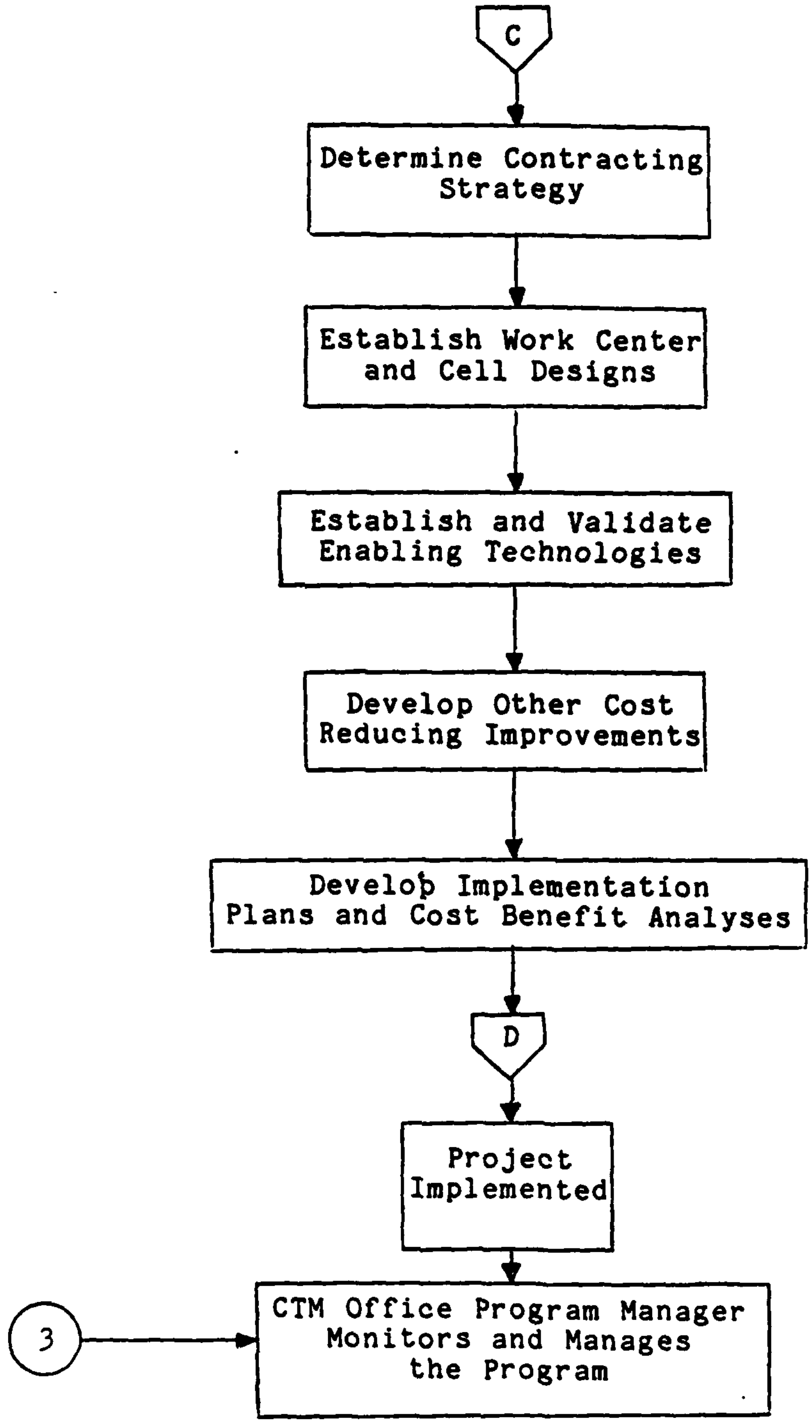

Figure 4.6. Centralized Tech Mod Office Decision Process (Continued)

efforts could prove most beneficial, and the CTM attempts to negotiate modernization arrangements with firms in those industries.

Selection of target industries within the aerospace base is strictly subjective and is based on political considerations and on CTM office perceptions of which industries will benefit the most and of where modernization will provide the greatest returns to the Air Force and DoD in terms of major system programs. Once target industries have been identified, specific firms must be chosen to participate in Tech Mod. Recall from Chapter 2 that there are four ways in which candidate firms are identified. Under current procedures, the CTM office decides to pursue Tech Mod in a specific industry and then contacts potential Tech Mod recipients by sending out an industry-wide RFP. Responses to the RFP are then evaluated in terms of the following criteria (70):

1. top management commitment,
2. potential government benefits, and
3. availability of funds.

Once again, the selection process is primarily subjective with degree of management commitment at candidate firms being one pivotal factor and government benefits (especially $ savings) as the other major consideration. Top management commitment is crucial to the success of any

Tech Mod endeavor; and unless a firm demonstrates a high degree of receptiveness, it will be dropped from further consideration. Equally important is the analysis of government benefits (projected). Often, savings on the instant contract (i.e., the contract in force) is the driving factor which leads to funding of a Tech Mod. Past award of Tech Mod contracts by the CTM office has always been accomplished through one-on-one negotiations. The award process has never been done as a source selection. Under this noncompetitive procedure, proposals have not had to be ranked or prioritized (70).

After one or more firms in an industry have been selected to participate in Tech Mod, the CTM office assigns a program manager to administer the Tech Mod; and the three-phase cycle begins. In Phase I, an immediate concern is determination of an appropriate contracting strategy. There are two options. The first is to add the Tech Mod to an existing contract. The second is to develop a new contract. Closely aligned with the choice of a contracting strategy is deciding the source of funds. Typically, the CTM office asks the contractor to fund Phase I (70). The result of the Phase I effort is identification of modernization candidate projects which have been screened on the basis of several criteria developed by the CTM office including:

1. feasibility assessment,
2. analysis of government savings,

3. assessment of government risk,
4. evaluation of business parameters,
5. generic application, and
6. DoD-wide impact.

The CTM office program manager assigned to a specific industry Tech Mod effort will generally work closely with the contractor(s) throughout Phase I and will usually know before Phase I proposals are submitted which projects will be selected. In fact, there is almost an informal understanding that the projects forwarded are the ones the government is interested in pursuing with that particular firm. Accordingly, these projects have already passed the test of feasibility; government savings (or other benefits) are substantial; government risk (monetary) is acceptable; the contractor has agreed up front how savings and incentives will be calculated and paid; opportunities for technology transfer are good; and the program has potential DoD-wide impact. (70)

From Phase I, the CTM office makes a final selection of projects to pursue and the cycle enters Phase II. In this phase, modernization plans and technologies are developed. The contractors forward implementation plans and CBA to the Tech Mod program manager for final review before Phase III implementation begins. Following implementation of enabling technologies, the CTM program manager monitors the Tech Mod to (70):

1. review documentation and track cost and schedule,

2. look for potential problems,

3. review contractor performance,

4. assess program effectiveness in terms of PBA objectives, and

5. look for opportunities for technology transfer.

The horizontal Tech Mod strategy is "a systematic, coordinated effort to attack problem areas and increase productivity throughout the aerospace industrial base [2:22]." As such, it targets all portions of the aerospace infrastructure which includes both prime and subcontractors. While the horizontal approach is new, indications are that the procedure will prove successful and that the application of Tech Mod utilizing a broad-based approach will be felt throughout the aerospace industry.

Conclusions

As can be seen from the case analyses of the vertical and horizontal perspectives of the Tech Mod process, and as stated in the ASD guide to Technology Modernization (2:25):

> Tech Mod is geared to the nearer term needs of the industrial base, . . . [and] . . . attempts to achieve early production floor implementation, while fostering an attitude toward longer term and continuing productivity improvement.

The only way to ensure that Tech Mod programs produce the expected and desired results as defined in Chapter 2 of this thesis is to select only those programs (and individual projects within programs) which are the best candidates and provide the best opportunities for success. To this end, ASD has developed a set of criteria for use when evaluating and prioritizing candidate programs and projects. The list contains the following subjective and objective considerations (2:25):

1. industrial base need,
2. return on investment,
3. lead time reduction,
4. increased flexibility (surge),
5. increased quality,
6. improved technological advancement,
7. technology transfer opportunities,
8. reduced critical materials needs,
9. multi-service potential,
10. improved private sector capital investment commitment, and
11. increased competition.

This list, while not all-encompassing, does provide a good starting point for evaluating potential Tech Mod programs and projects. However, to date, these criteria have not been extensively used in Tech Mod decision making. In fact, most decisions relative to selection of Tech Mod

programs and individual projects have been made on the basis of purely subjective considerations. While the quantitative data were available in most cases, they were largely ignored in favor of qualitative inputs such as a manager's feeling on potential success of a program and an assessment of management commitment.

Figure 4.7 presents a capsulized view of the decision process associated with Tech Mod programs reviewed in the course of this research. Tech Mod programs currently underway all conform to this general but basic decision structure. Throughout the sequence, decisions are made utilizing subjective or qualitative type information. This is not necessarily bad, and some quantitative data such as savings and cost have been considered (albeit subjectively); but, given the amount and type of objective data available throughout the process, consideration of such data could result in better selection of Tech Mod programs and/or projects within programs. One way to use objective data and add structure to the Tech Mod decision process would be to develop a contemporary Decision Support System (DSS) to aid decision makers involved in the Tech Mod selection process. A computer-based system of this type would be a powerful tool in support of managers and would serve to extend decision maker capabilities rather than to replace their judgement. An interactive DSS would enhance the effectiveness of the semi-structured decision processes managers are presently utilizing.

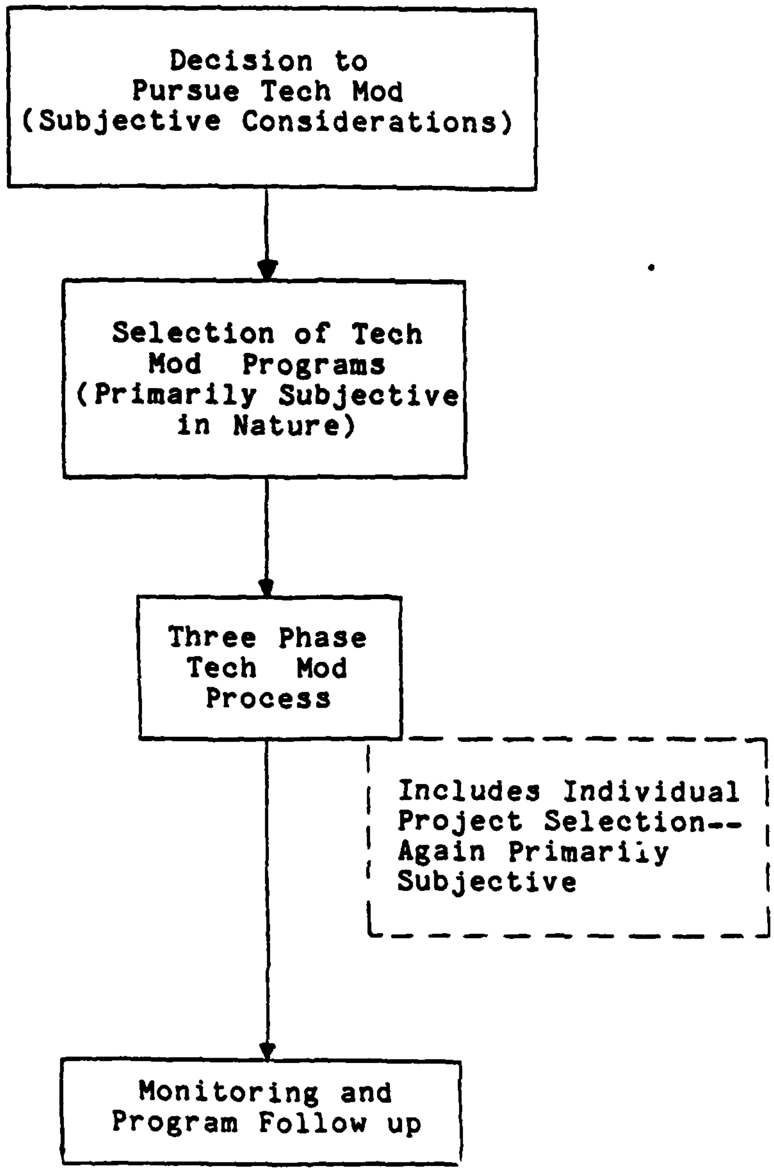

Figure 4.7. Synthesized and Simplified Decision Process

This chapter has provided what can be thought of as the descriptive framework of the Tech Mod process as it exists today within the AF acquisition community. The next section will present a generic conception of the Tech Mod decision process which is commonly referred to as the normative (or prescriptive) design. In essence, the normative view is a model of Tech Mod decision making which incorporates a DSS to aid managerial decision making.

V. Normative Model: Proposed DSS

Chapter Overview

In this chapter, a normative direction is identified from the descriptive models of the Tech Mod process. That is, the "descriptions" of the Tech Mod process from Chapter 4 are synthesized into a prescriptive conceptualization, which includes a DSS. Included are an explanation of model and DSS design followed by a detailed description of the model. The main purpose of the normative model is to provide a conceptual plan of the complex interaction and interrelationship of factors that do, or should, affect the Tech Mod process. However, as Adam et al. (1:113) point out:

> Conceptual models are necessarily less precise and less easily tested than are their physical counterparts; yet this should not be cause for omitting them from research efforts. Even an imprecise model aids in organizing thoughts, theories, and research results into a manageable set of interrelated concepts that can find practical applications . . ..

The model has immediate practical value in understanding some of the factors of the Tech Mod process, and was designed to provide greater practical benefits once

the "less precise" blocks of the model are expanded to include "more precise" measures. This model provides the reader with a macro view of the Tech Mod process as it should occur under ideal circumstances. Each block of this macro view should be scrutinized for potential expansion to obtain more concrete results, as has been done for the prioritization block (C10) in Chapter 6.

Design

The model was formulated from the "diagnostic perspective" suggested by Keen and Morton (42:77). That is, the descriptive models from Chapter 4 were used as a basis for the normative one. The normative model was developed to be both iterative and modular. It is (and needs to be) iterative because it must be able to adapt and change over time. This is important for two reasons--first, the model may be incomplete because this is the first attempt to formally structure the Tech Mod decision. Accordingly, there may be omissions forced by research time constraints and the state of knowledge in the area. However, the final version of the model was reviewed by several experts to reduce this type of error. The second reason for the iterative design of the model is the dynamic nature of the Tech Mod environment. Since the environment is uncontrollable, it must be closely monitored and acted upon as necessary (62:10). Changes in the decision process

attributable to environmental instability can be incorporated into the model through its iterative feature.

The modular aspect of the model (represented by the different blocks of Figures 5.1, 5.2, and 6.3) can be useful in implementing and changing the DSS. Since the model was not meant to be a "turnkey" system, the modular design allows it to be implemented in increments. The modular structure not only gives the decision maker the flexibility to add to and subtract from the system as required, but also facilitates changing the contents (or imbedded techniques) of the modules without affecting the rest of the process. For instance, the next chapter suggests use of a linear programming technique for the "prioritization" block; however, the decision maker could simply replace the block if he desired. If the decision maker wishes to use only intuition and experience as selection criteria, then the computerized portion of the prioritization block (C10) collapses to a straight line.

The model was also designed with a generic perspective. As a result, both the horizontal and vertical approaches are incorporated. For instance, the term "program" is used throughout the description as the basic decision making unit (DMU); however, the term "project" could be substituted for "program." In fact if all the individual projects within programs competed for Tech Mod dollars instead of just the programs, there should be more

benefits accrued. This would eliminate the funding for the less productive projects within certain programs while picking up funding for projects in programs that may not have been selected.

The Model

Figure 5.1 presents a macro picture of the normative process subdivided into five major sections (designated as blocks A through E on the diagram). Figures 5.2(A), (B), (C), and (D) provide exploded views of the major sections of Figure 5.1. Blocks in Figure 5.2 are labelled with the letter corresponding to the appropriate block in Figure 5.1. For example, blocks A1, A2, and A3 in Figure 5.2(A) are all subtasks of block A in Figure 5.1. When references to the flow diagram blocks are made, the following convention is used: the referenced block is followed by a set of parentheses containing the block number. For example, "C10A2" refers to that particular block in Figure 6.3, which is a subset of the parent Figures 5.2 (Block C10) and 5.1 (Block C).

The flow diagram is for the most part self-explanatory; however, a written description follows that explains the process in more detail. The explanation is categorized by the five blocks of Figure 5.1 and annotated with references from Figure 5.2(A), (B), (C), and (D).

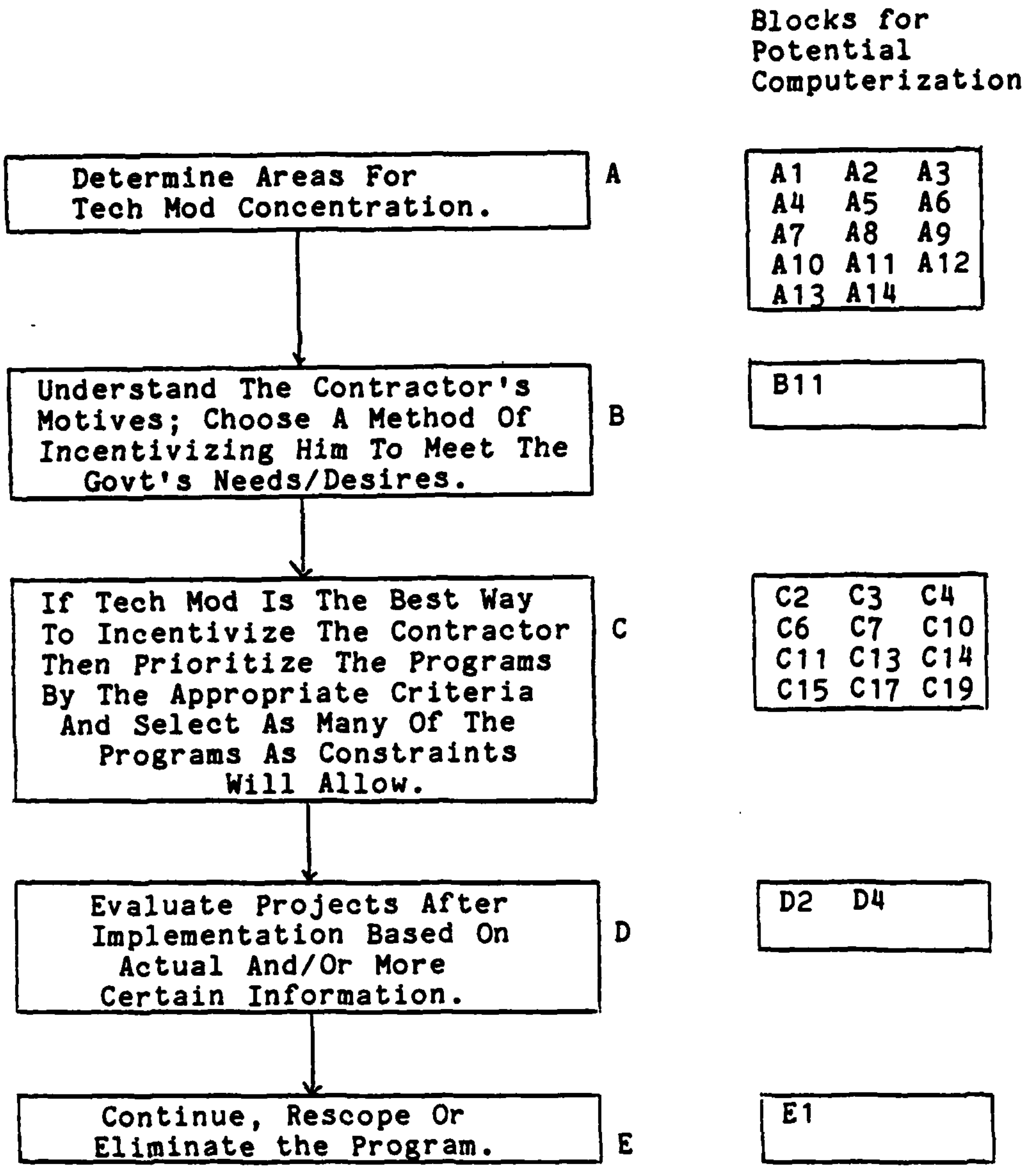

Figure 5.1. Macro Flow of Tech Mod Decision Process

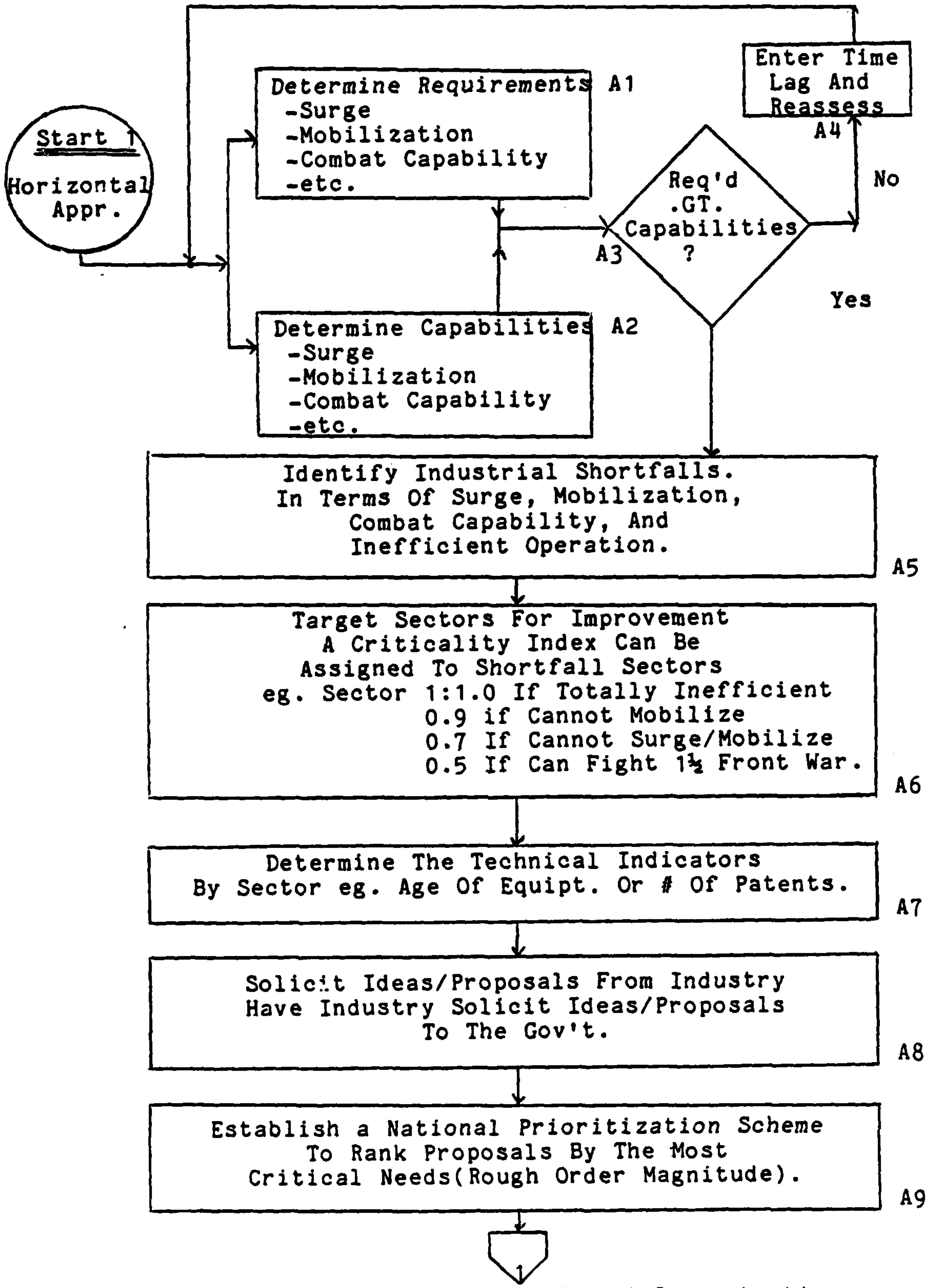

Figure 5.2(A). Determine Areas For Tech Mod Concentration: Block A

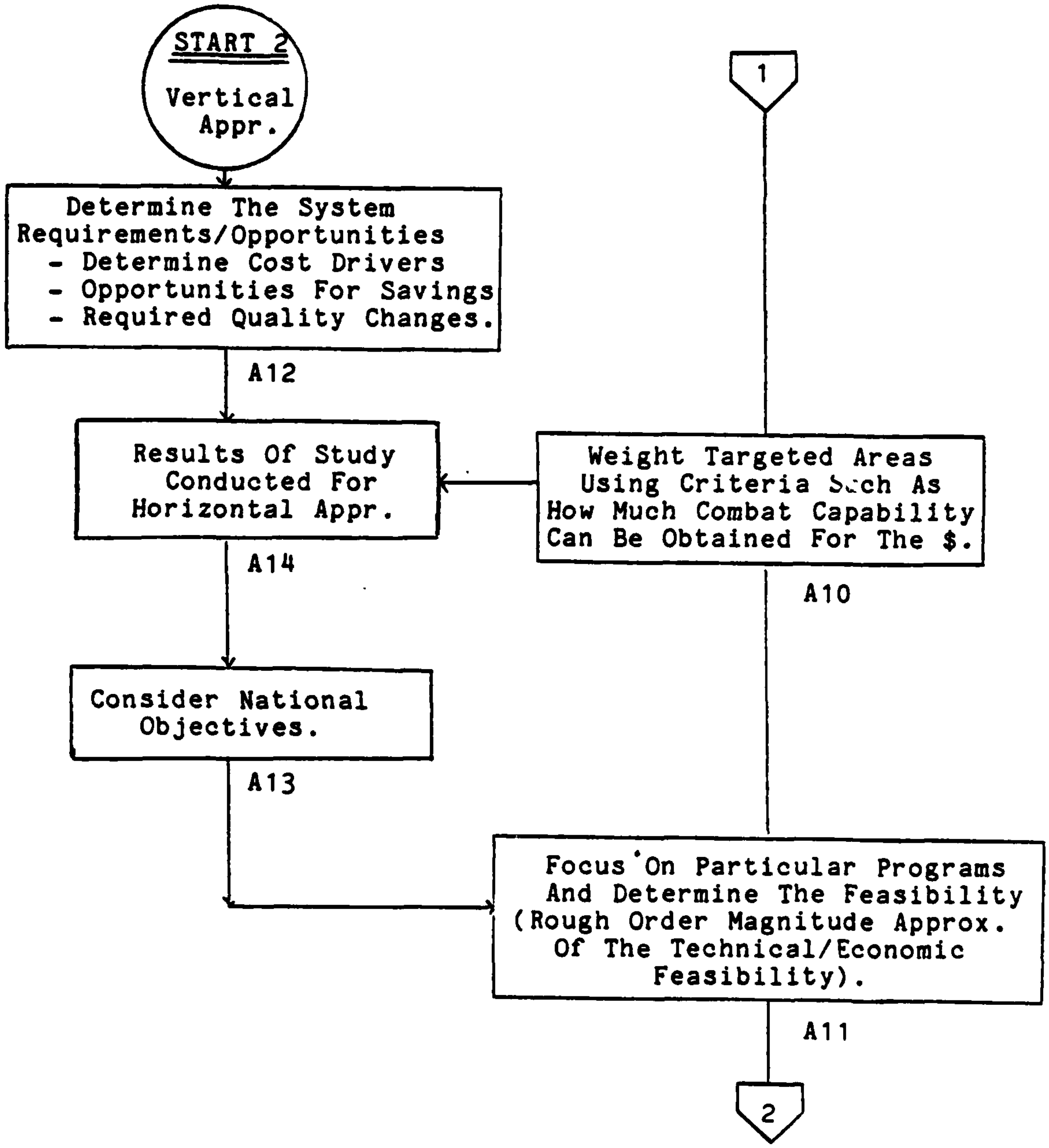

Figure 5.2(A). Determine Areas For Tech Mod Concentration: Block A (Continued)

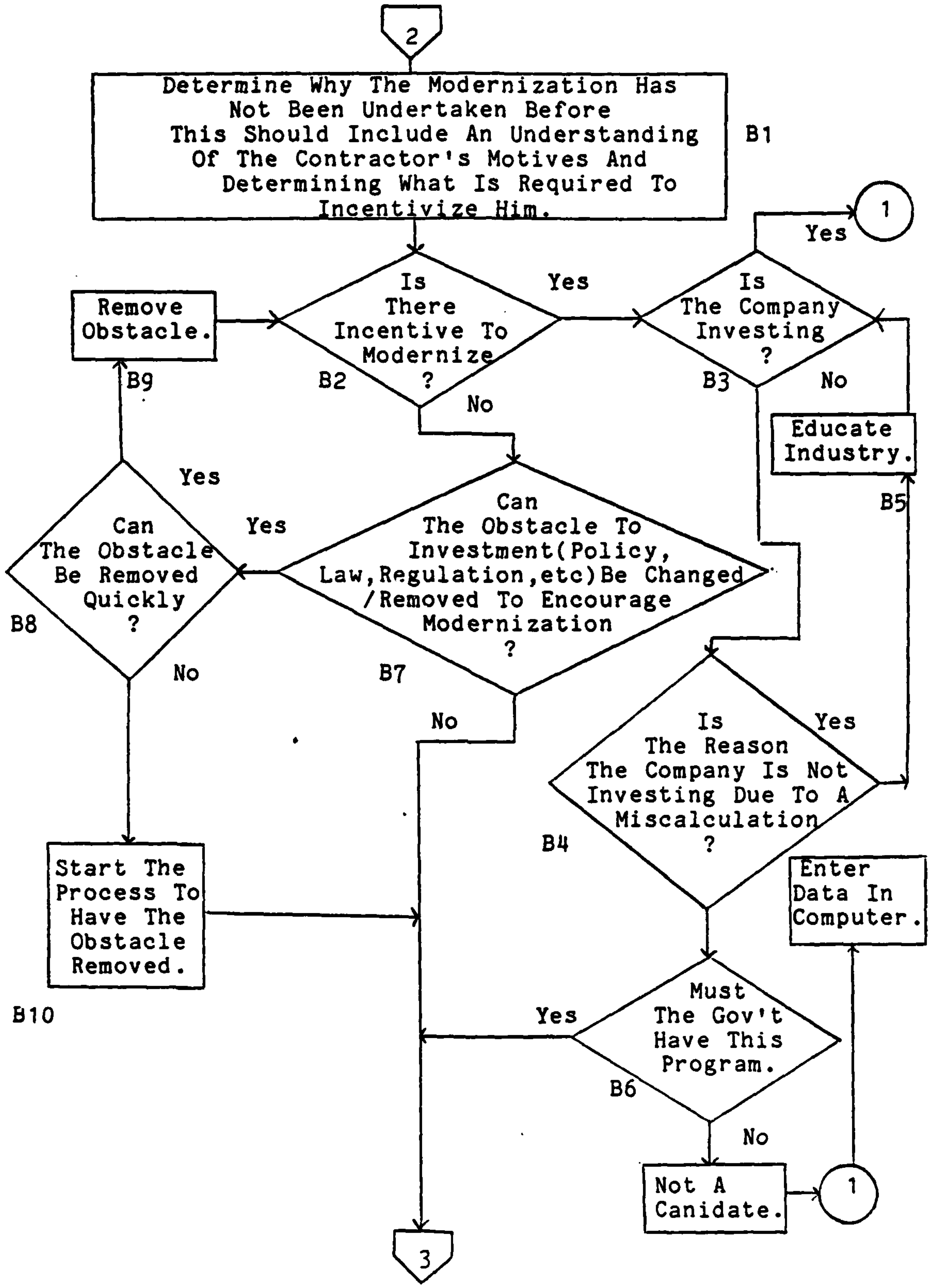

Figure 5.2(B). Understanding the Contractor's Motives: Block B

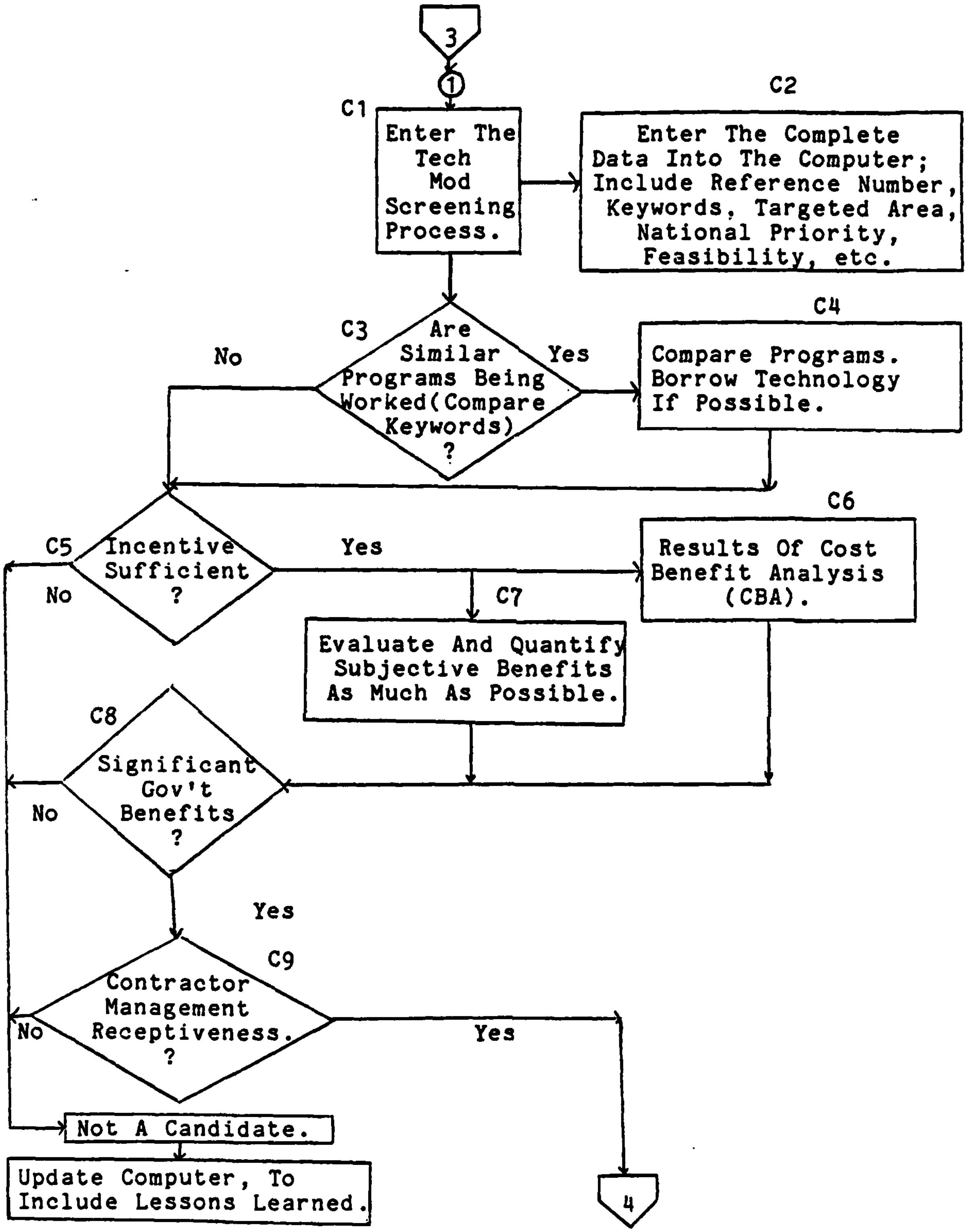

Figure 5.2(C). Screen, Prioritize, and Select Programs: Block C

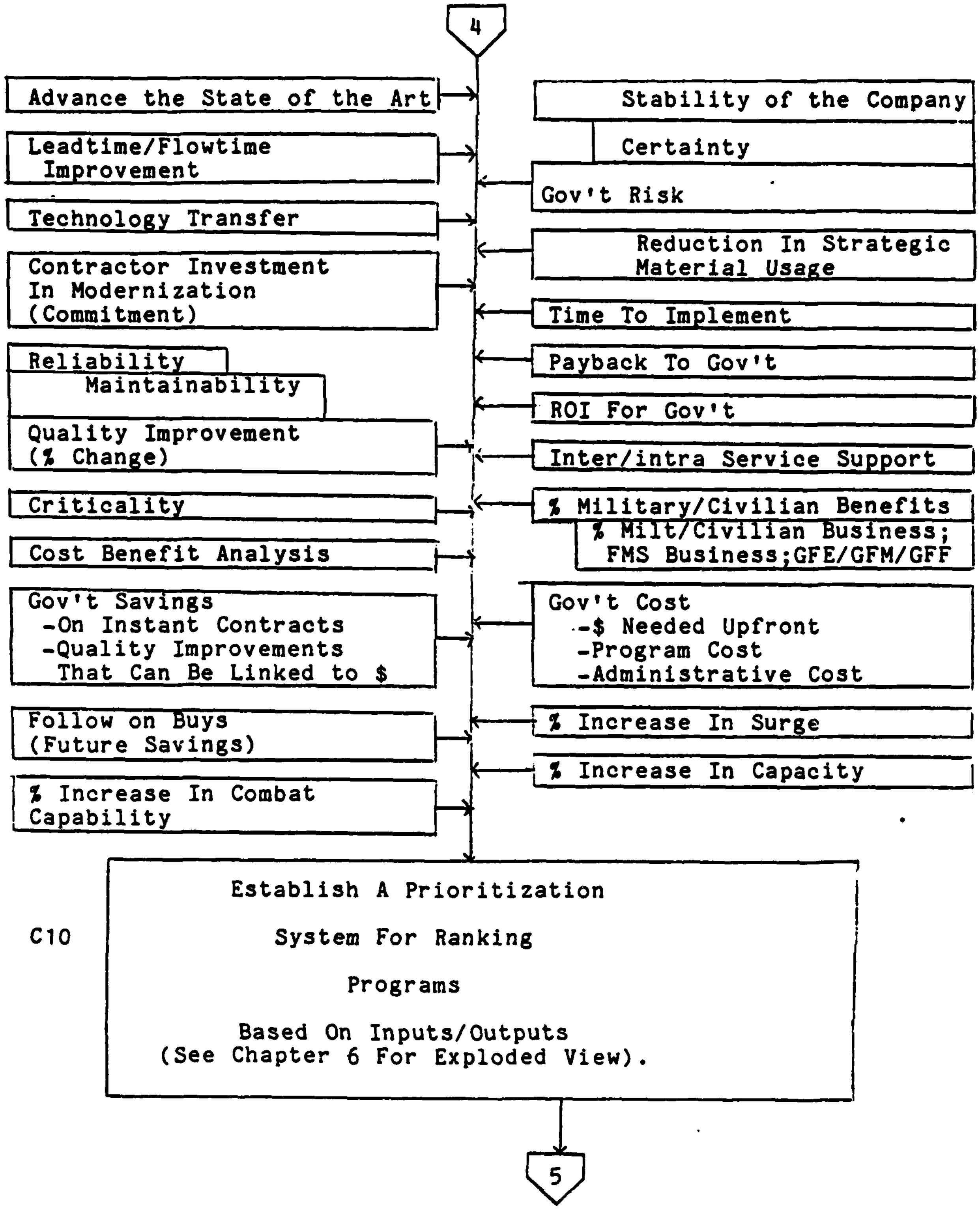

Figure 5.2(C). Screen, Prioritize, and Select Programs: Block C (Continued)

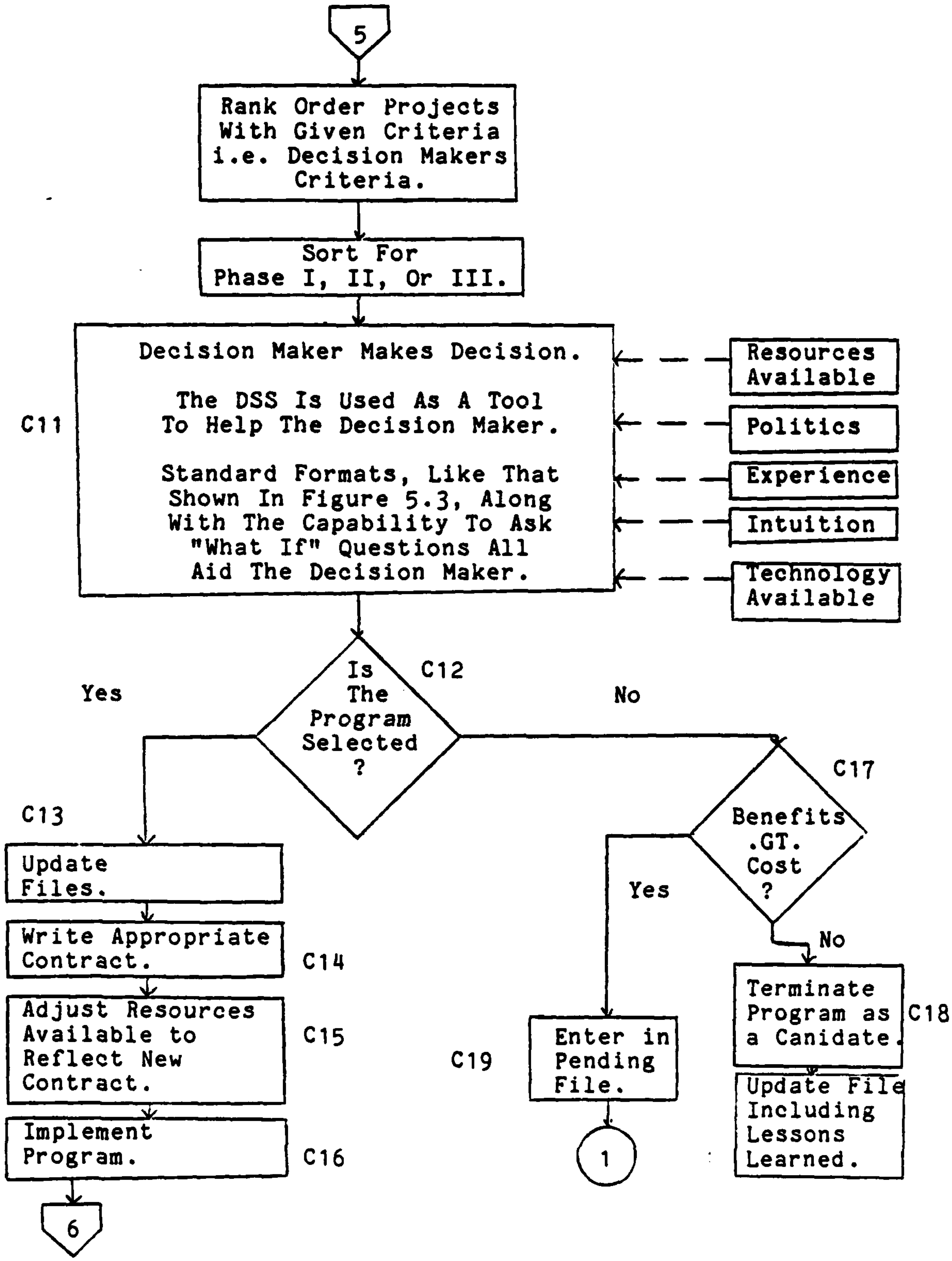

Figure 5.2(C). Screen, Prioritize, and Select Programs: Block C (Continued)

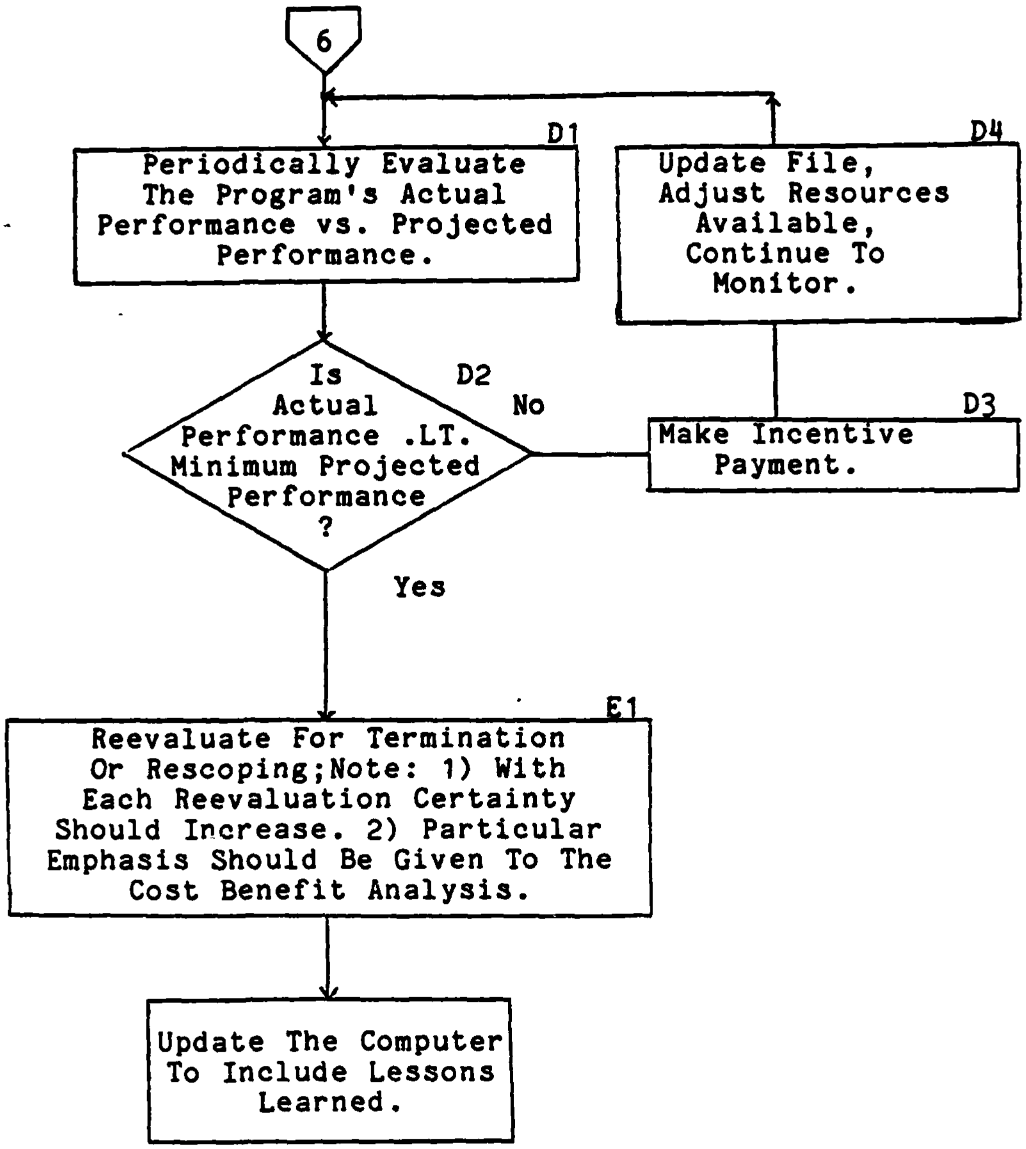

Figure 5.2(D). Post-Implementation Assessment and Action: Blocks D and E

Block A: Focus Tech Mod Efforts (Figure 5.2(A))

The Horizontal Approach. In order to determine specific areas where to concentrate Tech Mod efforts, it is necessary to first determine where shortfalls exist (A5). Then one should attempt to obtain the greatest advancement toward national goals and objectives for the resources (time, money, etc.) expended. Those advances very likely would be in areas with the greatest shortfalls. Such shortfalls can be identified by comparing actual capabilities to actual requirements (A1, A2, and A3). If shortfalls do not exist in a particular sector, then there is no impetus for Tech Mod at that time, and it will be some time before that industry is reassessed (A4).

National objectives establish requirements in macro terms. It is somewhat more difficult to progress from the macro national objectives of fighting a one-and-a-half-war scenario to surge and mobilization requirements, then to being productive, effective, and efficient, and then to the micro view at the working level where the objectives must actually be accomplished. It is the sum of the changes at the micro level that really impacts the overall situation. The impact of a single change at the micro level is often hard to detect at the macro level, but with few exceptions the macro level can be impacted only from changes made at the micro level.

1. Production Base Analysis (PBA). Since, for a Tech Mod to succeed, a program or project centered effort is needed; it is important to have the industry analyzed in detail. The first detailed production base analysis for aircraft, propulsion systems, and tactical missiles, Blueprint for Tomorrow, was completed in March 1984 (3). Because this recent study's concept was close to ideal, it will be described briefly here. The study was a joint Air Force and industry effort that drew on the experience of a wide cross section of the U.S. industrial base. The approach was straight forward; and the first step was to characterize the industrial base by identifying (1) cost drivers, (2) where investments were going, (3) lead times required on subcontracted items and end items, and (4) the capacity of industry being used.

The next step was to determine USAF surge and mobilization requirements. The study described surge as a "test of responsiveness" for a "come as you are" conflict, with a short time build up, without disrupting commercial production. Surge was operationally defined for aircraft as increasing production rates by a factor of one and one half (1.5) in 12 months and then sustaining that rate. Mobilization, on the other hand, was described as a "test of the breadth and depth of the industrial base." Mobilization was considered to be a national effort that would displace commercial products and facilities as required to increase

production of certain military end items by a factor of three (3) in 36 months.

Having established the above capabilities and requirements, the study panel concentrated its efforts in two major directions. The first direction analyzed was peacetime operations. This orientation included the four following categories: (1) facilities and processes, (2) subcontractors, (3) business environment, and (4) manpower and skills. The other study direction concerned emergency or crisis operations. This second orientation focused on military surge and mobilization requirements and industrial capabilities.

Specific conclusions and recommendations were then presented for many levels of government. These recommendations contained suggested thrust areas for modernization which helped crystalize national objectives. Recommendations were evaluated from many perspectives including those of the military, and those of primary systems contractors, subcontractors, and suppliers. The mostly subjective estimates of the cost and benefits on which the recommendations were based had substantial credibility due to the collective expertise of the panel that produced the study. The panel which performed the Blueprint for Tomorrow study included representatives from the fifteen top defense contractors, 100% of the airframe prime contractors, and 30 subcontractors and suppliers.

With the "big picture" information available from a Blueprint for Tomorrow study or a similar study, shortfalls could be readily identified (A5) and certain sectors or areas targeted for improvement. Determination of a specific order in which to approach the targeted areas would depend on how critical the areas were in meeting our national objectives (A6). A panel such as that created for the Blueprint for Tomorrow study could prove useful for setting the necessary priorities (A9).

Since all government operations have fiscal constraints, it is also important to emphasize the areas where we can achieve the most in terms of national objectives for the least cost (A10). Efficient use of defense dollars is an important consideration and must be taken into account from the beginning. One problem in determining which industry sector, programs within a sector, or projects within a program will make the most efficient use of the dollars is deciding what their cost and feasibilities are (A11). At the macro level of the Tech Mod process only a "rough feeling" of the proper direction coupled with some technical indicators (A7) can be produced. There are three major factors that will determine how accurate the emphasis (weights) given to the targeted areas will be.

The first factor is the expertise of the panel. Since much of the evaluation requires subjective judgement on the

part of the panel, members should have a large breadth and depth of experience. For instance, they should possess some knowledge of the desired direction of the nation, of what steps must be taken to achieve common goals, and should have an idea of what actions are feasible from an economic standpoint.

A second important factor concerns the technical indicators used by the panel (A7). A set of standard technical indicators should be developed, tested, and revised. It should be recognized, however, that each industrial sector may have different indicators; and some examples are age of equipment, number of patents in an industry (55:108), and amount of depreciation claimed on taxes. As technical indicators prove to be more reliable, the amount of subjective evaluation can be reduced.

The third major factor that determines the accuracy of the weighted, targeted areas would be the degree to which industry experience could be tapped (A8). Industry is often thought of only in an adversarial role to the government, but a "team effort" is required to obtain the best results. This team effort should foster an exchange of ideas between the government and industry which would enhance the chances for success (A8). Industry should feel free to express their ideas to the government. Both the government and industry should approach this exchange as a "win-win" relation; i.e., their ideas should be of mutual benefit (2:69).

Once areas have been targeted and weighted (A10), a rough prioritization system can be established. The focus of the Tech Mod effort then can be directed toward the establishment of particular programs or projects which provide the most benefits for the cost (A11). A logical first step in determining which programs can potentially produce the most benefits for the cost would be to complete a preliminary study of technical and economic feasibility (A11).

<u>The Vertical Approach.</u> The vertical approach is driven by a particular major program and as such focuses on that program. The areas of emphasis include major cost drivers, opportunities for savings, and required quality changes (A12). As a secondary consideration, the decision maker should perceive how the particular modernization program under review fits into scheme of the national modernization program. Given a choice of several Tech Mod programs, the decision maker should choose the one most beneficial to his particular system (A11) as long as the program does not conflict with national objectives (A13). The results of the study conducted for the horizontal approach should aid the decision maker in determining the national objectives (A14). In the vertical approach, it seems intuitive that since the acquisition is being paid for by public funds, it is in the national interest to make that acquisition in the most efficient manner possible. However,

the vertical approach can result in the elimination of potential programs from consideration due to the requirement that the Tech Mod be program specific. This program specific orientation reduces competition for Tech Mod dollars and gives an unfair competitive advantage to the candidate already under contract with the SPO that controls the Tech Mod dollars. As can be seen, except for the scope of consideration, the decision process for the vertical and horizontal approaches are the same from this point on.

With the appropriate perspective, the decision maker then should narrow the scope of consideration to include only those programs which seem to be both technically and economically feasible (A11). Economic feasibility should be determined by a cost-benefit analysis. The benefits considered are not limited to dollars alone, but include such benefits as improved quality, performance, or flow time.

Block B: Determine How to Incentivize the Contractor (Figure 5.2(B))

Traditionally in the U.S., government involvement in the economic marketplace has been considered "bad." According to classical economic theory, the forces of supply and demand will eventually cause a situation that is optimal for society, that is, a situation where supply equals demand, and where industries reach equilibrium with each firm attaining its most efficient size and producing and

selling at its lowest market price. There are, however, two readily apparent problems with this classic theory in relation to government acquisition. First, the DoD marketplace is often not a competitive arena; second, competitive peacetime efficiency is a secondary consideration to effectiveness in contingency situations. Industry contingency requirements, such as the need for excess capacity, may conflict with the peacetime efficiency goals that would otherwise exist in a realistically competitive situation.

When industry is not responding to the government needs, then the reasons why should be investigated. By first understanding contractor motives, appropriate incentives can be applied to affect their responsiveness (B1).

Ideally, government policy (such as IRS policy), laws, and DoD contracting policy and regulations would incentivize contractors to invest on their own (B2). If these laws, regulations, or policies pose an obstacle to the investment objective then they should be changed (B7) assuming the change would result in more benefits than costs. If this "obstacle" could be changed quickly, there would be no need for Tech Mod (B8, B9). If the obstacle to investment can be removed but will take a long time or if the obstacle cannot be removed, then Tech Mod may be a viable alternative (B7, B8, and B10); and it is at this point that the Tech Mod screening process begins (C1).

On the other hand, if there appears to be sufficient incentive to invest and the company is not investing (B3), the government should determine why. In determining this, government and industry need to work together as a team. One of the first areas to investigate is how the company performed the cost benefit analysis during its decision not to invest. If a significant flaw in the analysis can be detected (B4), then identification of the mistake may convince the company to invest (B5). Another reason the company may not have invested in various modernization projects is that the company could not determine precisely where modernization would be most beneficial. Phase I of Tech Mod will help overcome this uncertainty by pointing out areas of potential benefits and determining costs and benefits of implementing (B5). Regardless of the reason, if DoD needs a company to invest and they are not, then the government must incentivize the company to do so (B6). Having exhausted more efficient means of incentivizing the contractor to invest, it is time to enter the Tech Mod screening process (C1).

Block C: Prioritize Programs (Figure 5.2(C))

From the beginning of the Tech Mod process, it is important to keep track of all programs and projects under consideration. One of the easiest ways to do this would be to enter them in a computer data base with a keyword structure that would allow cross referencing of data (C2).

The data base created will be an integral part of the decision support system for Tech Mod. One of the first requirements of the computer system would be to compare projects and determine if similar ones are being worked or have been worked (C3). Applicable transferable technology should then be incorporated into the project under consideration (C4).

AFSCR 800-17 states there must be insufficient competition and significant government benefits for a program to be awarded a Tech Mod contract. It is felt that, in general, insufficient competition during peacetime is a relatively good surrogate measure of insufficient incentive to invest (C5). However, there are some instances even in a perfectly competitive market when Tech Mod would be appropriate. For instance, surge and mobilization requirements may require plants to run at 70% of capacity. Since the competitive market eventually drives a firm to its most efficient size to meet demand, there would be little or no excess capacity to meet surge or mobilization requirements. In this instance, a contractor would have to be incentivized to maintain excess capacity. This could be accomplished through such incentives as tax breaks or Tech Mod incentives.

A second requirement, by regulation, is that significant benefits to the government must result (C8). Benefits should not be limited to just savings and cost

avoidance (C6), but should also include such considerations as quality, surge, and capacity (C7). The initial cost benefit analysis (CBA) should contain at least enough detail to determine if significant benefits will result for the government. As the Tech Mod progresses, the CBA will be updated, removing more and more of the inherent uncertainty.

In addition to contractor incentive and government benefit considerations, one must also consider contractor management receptiveness (C9). Since government and contractor teamwork is such an important aspect of Tech Mod, lack of strong contractor support will surely cause the program to fail (33; 43; 54; 70). One indication of contractor support is the amount of money the contractor is willing to invest in the project.

With all the above criteria met, the next problem would be prioritizing the programs (C10). One of the major problems in prioritization of projects is to find a standard means of comparison. This is very difficult for several reasons. First, there is no standard set of criteria used by decision makers in formulating their decisions. Second, most decision makers agree they should consider factors like surge, mobilization and capacity; but they do not know how. The third reason is the complexity of the factors considered and the complexity of their interactions. Many factors are much more complex than an objective measure would lead one to believe. There are many subjective measures that vary

with external influences. It is not the intent of this thesis to suggest the best way to evaluate subjective criteria; however, the SMART technique (57) appears to have some merit.

The linear programming technique known as Data Envelopment Analysis (DEA) is suggested for program and project prioritization. This technique, developed by Charnes, Cooper, and Rhodes (22) rates a unit's efficiency using multiple inputs and outputs. With some modification, this method has the potential to be one of the decision maker's most useful tools in prioritizing projects. Since a DSS would have capabilities for handling the calculations internally, only the general method and potential uses will be described here. Chapter 6 will expand the prioritization block, explain why DEA was chosen, describe the concepts of the DEA process, suggest how DEA can be employed for prioritization with the results of computer runs from some sample data, and finally, explain the managerial implications.

The computer prioritization is just one input into the decision making process. The decision maker should be able to display other program or project related information by asking for it. The formats of display information can be tailored to the individual decision maker. An example output is shown in Figure 5.3. Other computer products would be indentured under each heading. For example, "government

Project Number*	Project Name & Phase	Firm ROI	Govt ROI	Cost	Benefits**	Ranking
⋮	⋮	⋮	⋮	⋮	⋮	⋮

Payback Period	Start Date	Completion Date	Commitment	Percent Military/ Civilian Business	Last Update
⋮	⋮	⋮	⋮	⋮	⋮

*This is one suggested format. Each decision maker would have a format designed specifically for him. Each decision maker would also designate the criteria to be used in ranking projects. The outputs would normally be in a standard format, but the program would be user friendly and allow the decision maker flexibility in obtaining other information by asking "What if" questions. Comments of the analyst would follow each project automatically if something in the standard format needed explaining, otherwise comments could be requested with an easy command.

**Example: \$10.4M savings; capacity of TWT industry increased by 8%; efficiency of plant increased by 14%; current shortfall in TWT industry-14%; projected shortfall in 5 years with Tech Mod-6%; projected shortfall in 5 years without Tech Mod-12%.

NOTE: Each user will have limited "READ/WRITE" capability as determined by the situation. For example, if a contractor has access to the computer he would not have access to "contractor sensitive" information. Also, only certain organizations or persons would have WRITE capability and would be held accountable for its content.

Figure 5.3. Sample Program Summary Form

ROI" may have indentured information on how it was calculated to include what cost, what savings, and what interest rates were used.

The decision maker then makes a decision based on the computer product, resources available (manpower and money), politics, experience, intuition, and available technology (C11). Resources available and technology available are, for the most part, established constraints. In the normative process, politics can help integrate Tech Mod with its environment; however, politics is a one-sided means to a minority goal (e.g., program-specific), and should be avoided. Experience and intuition is a cornerstone in the current decision process and will remain a cornerstone in the normative one. In fact, a DSS is not meant to replace, but rather to supplement a decision maker, and experience and intuition provide greater breadth and depth to a decision than is possible with specific but incomplete information.

Once the decision to begin a program in Phase I, II, or III is made, some type of contract must be established. The description of Phase I and Phase II should be included in the initial acquisition plan and the Determination and Findings (2:61). However, it may be best to have a Tech Mod contract separate from the system contract so the Tech Mod program is not just program-specific (2:61-62). The type of contract should depend mainly on the risk associated with

the program. If risk is low, as in a Phase I factory analysis, a firm fixed price would be appropriate. If risk increases, as in Phases II and III contracts, the government would be expected to assume more of the risk.

If programs are not selected to enter into Phase II or III yet benefits are greater than cost (C17), then they should be entered in a pending file (C19) of contracts to be considered for implementation if money becomes available. Planning is important and will enable the government to seize investment opportunities such as these. Because of the design of the budget process, funds may become available on short notice; and if no prior planning is completed, the decision maker may have to select programs that are not as "good" as those that were turned down earlier; or he many not be able to select any programs due to the lead time required. By establishing a pending file of contracts, a decision maker is given more latitude in choosing programs. Since cost and benefits vary over time, a pending file would have to be updated on a routine basis. However, only the most promising programs need to be kept current. Similarly, if benefits are less than costs, the programs (C17) should be terminated (C18) and any lessons learned entered in a file.

Block D: Evaluation (Figure 5.2(D))

In addition to selecting and awarding Tech Mod programs, the decision maker should also evaluate the

results of his decisions (D1). This evaluation should have three positive effects. First, it should give the decision maker something concrete on which to base incentive payments (D2 and D3). Second, it should provide a means for determining if the project could be rescoped or terminated (E1). Finally, the feedback from an evaluation should help provide the decision maker experience and intuition which will aid in other Tech Mod decisions. Such feedback may cause him to change his selection criteria or possibly change the structure of his Tech Mod decision process.

Since post assessments can cost as much as the projects themselves, only the level of post assessment required to achieve the desired objectives should be accomplished (33). Determining the appropriate method and level of assessment is a possible area for future research.

Block E: Program Review (Figure 5.2(D))

The output of the evaluation block provides a means to determine what action to take on the program under study. Typically, the decision should be to continue the program as planned in the "business deal" (E1). However, if performance is below minimum expected (D3), then one should suspect the original estimates to be incorrect. Another CBA should then be completed to determine what action to take on the program. If, for instance, part of the program is working and others are not, the project should be expanded or narrowed so as to take advantage of the actual situation.

If all or most aspects of the program are not performing adequately then the project should be terminated.

Summary and Conclusions

Chapter 5 developed a normative model for the Tech Mod decision process. The process as presented can be useful in several areas. First, it can serve as a guide to the decision maker. Even though not all areas addressed in the system are quantifiable, there is still much value in considering them. By considering these areas, the decision maker will affect his decision by influencing his own intuition and judgement. The second major implication of the DSS developed is as a baseline for future research. The system was intentionally designed to be iterative and modular. The researchers used these attributes to incorporate more information as it became available, thereby going through several iterations of changing various modules. An illustration of an iteration that expanded one of the modules (blocks) is presented in the next chapter.

VI. Tech Mod Prioritization: Expansion of Figure 5.1, Block C10

Chapter Overview

This chapter demonstrates a partial expansion of one of the DSS modular blocks--the Prioritization block C10 from Figure 5.2. This chapter suggests use of a linear programming (LP) technique as a generic prioritization method in support of the Prioritization block (C10). The LP technique is known as Data Envelopment Analysis (DEA) (with some extensions), and its possibilities as a ranking technique are explored herein. In addition to suggesting the DEA method, this chapter explains why DEA was selected over other available techniques, describes the concepts of the DEA process, suggests a methodology to be followed from gathering data to prioritization of programs and projects, and finally, explains some of the managerial implications of the results.

This chapter does not suggest or attempt to establish the precise quantifiable inputs that should be included in the prioritization model for ranking programs and projects; rather, it presents a technique flexible enough to allow a decision maker to rank projects[1] on the criteria he desires. A decision maker may choose to include objective data, a

subjective evaluation that has been "quantified," or some combination of the two in the model.

One should keep in mind this technique is in the setting of a DSS; and as such, the details of the calculations will be omitted except where necessary to understand the concepts. The thrust of this chapter is to give the decision maker sufficient understanding of the methodology so he may interpret the results and be able to ask the appropriate questions to obtain the desired information. Though the orientation is toward the decision maker's interpretation of the results, enough references (Appendix and other sources) have been included to allow a designer to implement the system.

Why Linear Programming?

The key question in a prioritization scheme for Tech Mod is how to compare one contract to another. If government (in this case, the Air Force) were a profit organization, the comparison would be much simpler because "profit provides an overall measure of both effectiveness and efficiency [13:39]." In nonprofit organizations, however, there are multiple, conflicting objectives and "no overall measure of performance [13:39]." Lacking a specific standard to rate units against, other attempts are made to combine inputs/outputs into one measure. One attempt to aggregate multiple inputs and outputs into an overall

measure is the concept of ratio analysis. Ratios can be divided into two major categories: partial ratios and complete ratios.

Partial Ratios

Often when ratio analysis is used, less than the full set of inputs and outputs are considered and, consequently, only a partial ratio is determined. For example, a partial ratio sometimes used is return on investment (ROI) where:

$$\begin{aligned} \text{ROI} &= \text{RESULTING INCOME(\$)/CAPITAL INVESTMENT(\$)} \\ &= \text{ONE OUTPUT (INCOME)/ONE INPUT (COST)} \qquad (6.1) \end{aligned}$$

This particular ratio can be, and is, used as a partial measurement of the acceptability of a Tech Mod proposal. If a decision maker were to use ROI as the sole basis for his decision, he may be neglecting other important factors such as management commitment.

Total Factor Ratios

A second possible type of ratio is the more comprehensive total factor ratio. Mali (48:91-2) suggests

$$\text{TOTAL FACTOR PRODUCTIVITY} = \text{OUTPUT/ALL INPUTS} \qquad (6.2)$$

As an acceptability measure for a profit making organization a comprehensive total factor ratio may be a much more complete measure than ROI.

increased mobilization, and increased quality. The measures of these inputs and outputs and the weights they are assigned are critical to the decision.

Due to the complexity of weighting a multiple input/output situation, ratio analysis as described above was considered inappropriate for an interactive, manager-oriented DSS. The purpose of any DSS, and the purpose of proposing one in this study, is to aid a decision maker and add some structure to his decision making process. To accomplish this it is essential that the DSS incorporate methods and techniques which are both understandable and attractive to a decision maker, otherwise the DSS will not be used. A technique which simultaneously takes into account all inputs and outputs and then interacts is preferred to one which requires the use of multiple ratios and which requires a priori assignment of weights.

Data Envelopment Analysis (DEA)

DEA is a linear programming technique that allows one to consider multiple inputs and outputs without requiring common units of measure (17:2-3). This technique will rank units (potential programs or projects, in this case) relative to other units based on data supplied. Rhodes (1), Clark (25), Bessent and Bessent (16), and Sherman (63) are a few of the pioneers who have demonstrated the usefulness of DEA in not-for-profit organizations.

DEA affords a good deal of flexibility. This technique allows decision makers to obtain an overall rating of units relative to a set of criterion units. DEA was chosen as the basis for the prioritization block for the following reasons:

1. DEA in its simplest form (one input and one output) is equivalent to ratio analysis,

2. DEA ratings are insensitive to the scale of the measures used, and the inputs and outputs need to be expressed in common units of measure,

3. DEA makes no assumptions about the distribution of the data,

4. DEA makes no assumptions about the production function,

5. DEA does not require an absolute (theoretical) standard to rank units (even though one may be applied if it is known), but rather, defines its own relative standard derived from the data,

6. DEA is a relatively new area that has been demonstrated to be an effective tool for managing not-for-profit organizations,

7. DEA is a flexible technique that has potential in areas of contract management beyond prioritization, and

8. software is available (23) so DEA may be implemented on various computers including home mini-computers.[2]

DEA Description

DEA is a linear programming technique that can evaluate each of many multiple input and multiple output combinations to determine relative "efficiency frontiers"

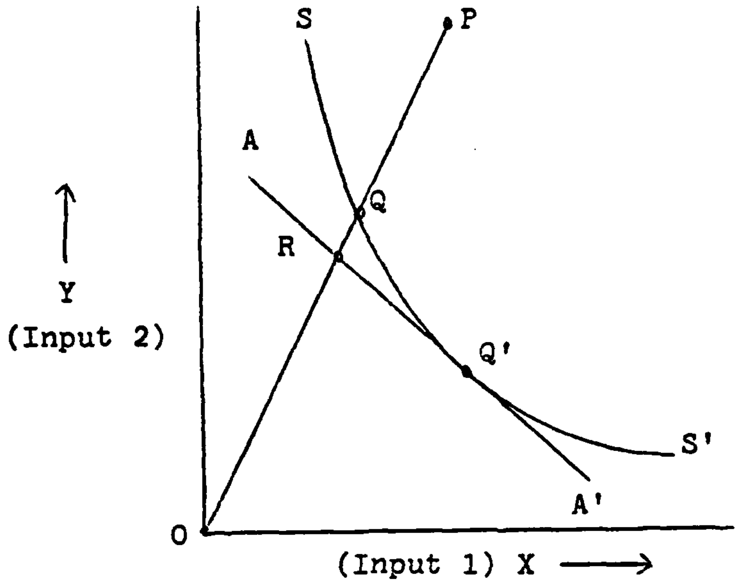

Figure 6.1. Farrell's Efficiency Isoquant

against which all combinations are rated. The idea of the "efficiency frontier" was first proposed by Farrell (32). Farrell's concept can best be illustrated by referring to the two input-one output case shown in Figure 6.1. Line SS' represents the various combinations of two inputs a perfectly efficient firm would use to produce one unit of output where efficiency ratings can range from 0 to 1.0. Line AA' represents the marginal rate of substitution (instantaneous slope) of the curve for the efficient combination Q'. The point P is inefficient since it produces the same output as Q, but requires more inputs. Farrell (32:254-255) illustrates three types of efficiencies: technical, price, and overall.

Technical efficiency for P is shown to be OQ/OP where Q is an efficient input combination which has the same mix of inputs as P. One can see from the diagram that P is measured relative to only one point--Q. Consequently, if one knows the mathematical formula for the frontier isoquant SS', then one has a standard against which the technical efficiency of each input combination can be measured. For example, Q' is efficient and one would not be expected to improve on that combination (assuming SS' is not an advancing frontier[3]). Furthermore, a comparison of P and Q' would not be appropriate for determining technical efficiencies since P has less of input X than Q' has yet more of input Y; i.e., the points P and Q' have a different mix of inputs. There have been several applied studies that have shown the technical efficiency concept to be useful in targeting management attention toward sources of inefficiency (16; 25; 59; 63).

"Price" efficiency for Q is shown to be OR/OQ if AA' is the budget line which means that Q' is determined to have the most economical mix of inputs. Though Q is efficient (i.e., it has a "technical efficiency" of 1.0 or 100%), Q' is preferred because Q' is the point of tangency between the budget line AA' and the frontier SS' which means Q' is the point of minimum cost.

Farrell further extends the point concept of price efficiency to include an overall measure of efficiency. The

overall measure for P relative to the mix of inputs that Q' has is OR/OP provided of course that the per unit costs of inputs are the same for both P and Q'. In a similar manner, all units could have an efficiency determined relative to the line AA'. Units could then be prioritized based on their efficiency ratings.

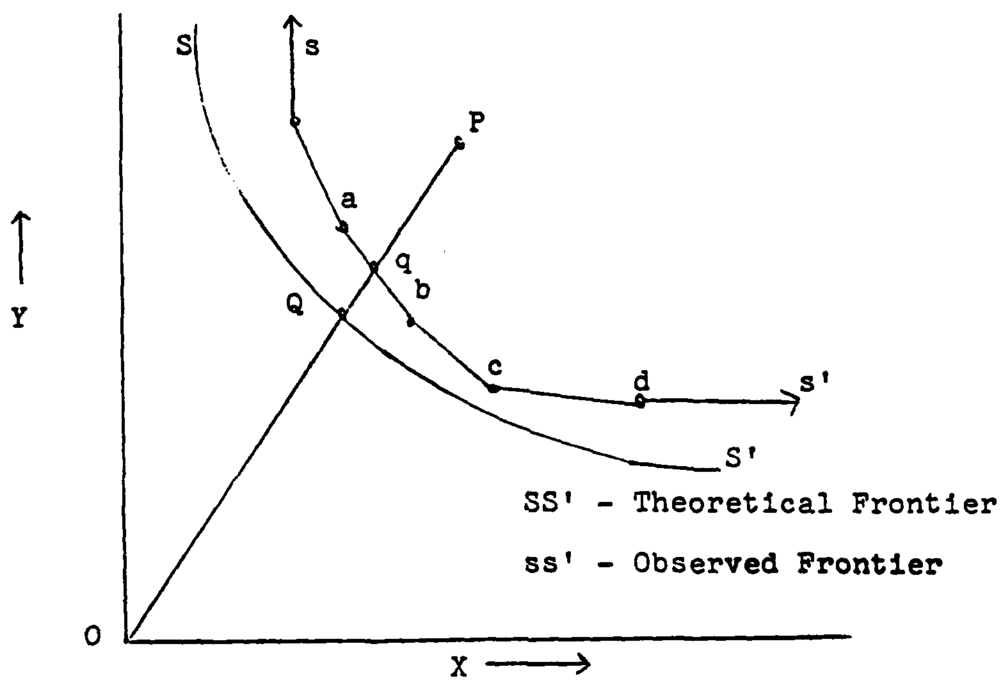

Figure 6.2. Piecewise Linear Efficiency Frontier(ss')

The above discussion of efficiency is based on knowing the shape of the isoquant (or production function) SS'. The theoretical shape of SS' can be approximated with a piecewise linear frontier formed from the best of a set of observed units (see Figure 6.2). One may note that the relative technical efficiency of p (Oq/OP) will be determined from observed units a and b. P is said to be

enveloped by a and b. The accuracy of this efficiency rating will depend on how closely the relative frontier formed by units a and b approximates SS' in the neighborhood of Q. One should not infer from the observed values that units a and b have no room for improvement (unless they were on the theoretical frontier), but one can infer that units a and b are more efficient than P. Consequently, if the units were prioritized on technical efficiency or on an overall efficiency (relative to a price efficiency defined by facet ab), a and b would both be rated higher than P. That is, $Oa/Oa = Ob/Ob = 1$ would be $> Oq/OP$ because $Oq < OP$.

The two input, one output case was presented for ease of illustration; but the concept can be extended to multiple inputs and outputs, the major difference being a complex multi-dimensional model. If three inputs and one output were used, the piecewise linear frontier described previously and shown in Figure 6.2 would become a piecewise linear frontier made up of triangular plane segments instead of line segments where each plane segment is defined by the combinations of the three inputs in three efficient units.

Computerization

Charnes, Cooper, and Rhodes (22) developed a linear programming model to solve the multi-dimensional problem discussed by Farrell. Their formulation involved changing the nonlinear efficiency ratio problem into an equivalent linear one. To see the equations required for linear

programming, refer to Clark (25:17-20). The derivation of the DEA model can be found in Charnes, Cooper, and Rhodes (22) and the derivation of an extension to DEA called Constrained Facet Analysis (CFA) can be found in Clark (25:82-122). It is not the intent of this thesis to describe the linear programming procedure in detail, but rather to discuss how the manager may use this "tool" that has already been developed. However, since this thesis will extend current research taking into account Farrell's concept of overall efficiency, more detail will be given in the overall efficiency area. The next section of this chapter will describe how a manager might incorporate DEA into his decision process followed by a section on how he should interpret the results of the model.

Suggested Procedure

Figure 6.3 depicts a suggested procedure for prioritization which a decision maker might use. The rest of this section describes the prioritization method. Like the entire DSS described in Chapter 5, the expansion of block C10 is also an iterative and modular process, that is, a process which can be improved from time to time and one in which the individual blocks can be expanded or changed without affecting the rest of the system.

Screen Inputs and Outputs (C10A). Screening the inputs and outputs can take two basic forms. The first would be to choose the appropriate input and output

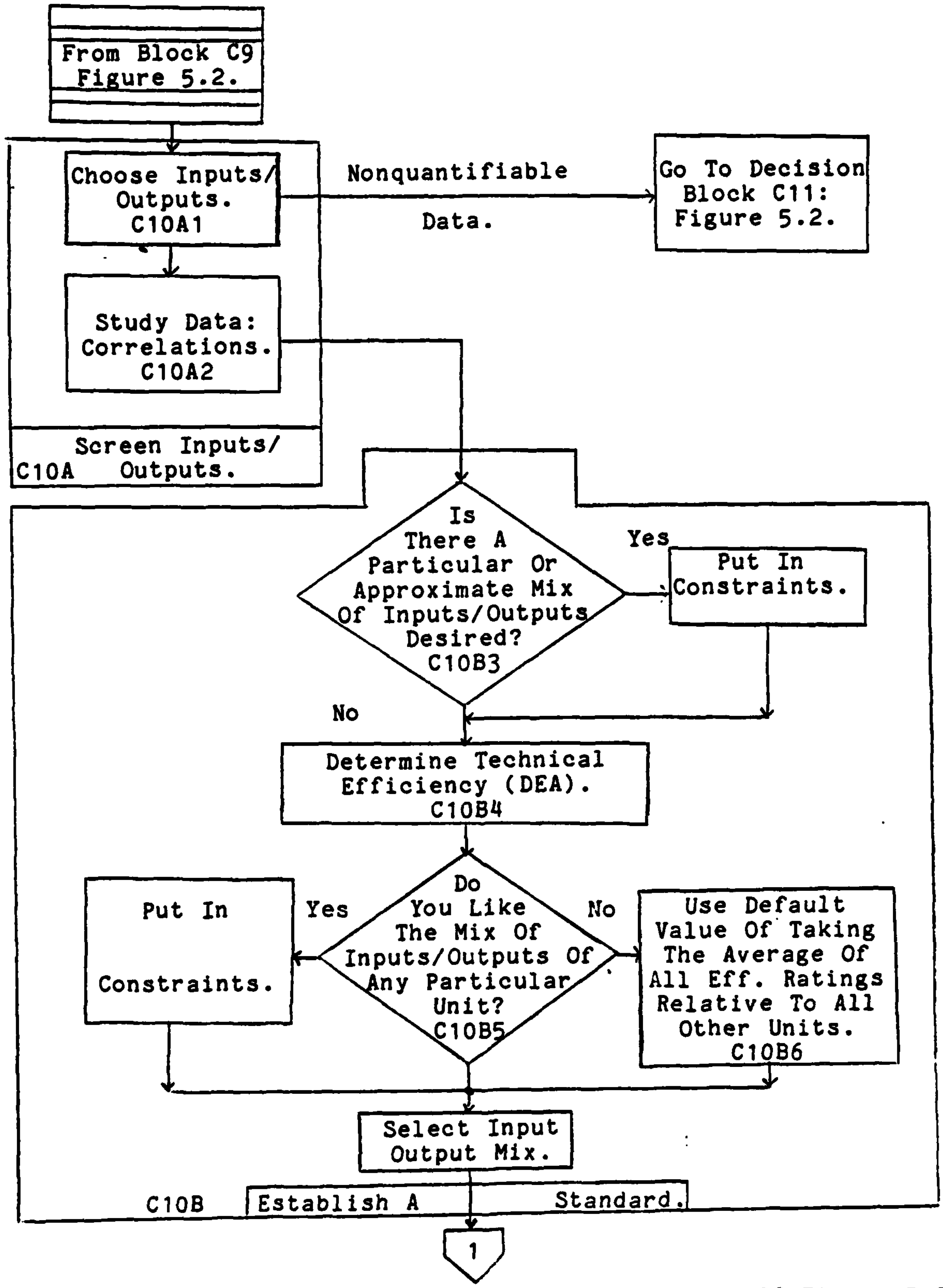

Figure 6.3. Suggested Procedure For Block C10 Of Figure 5.2

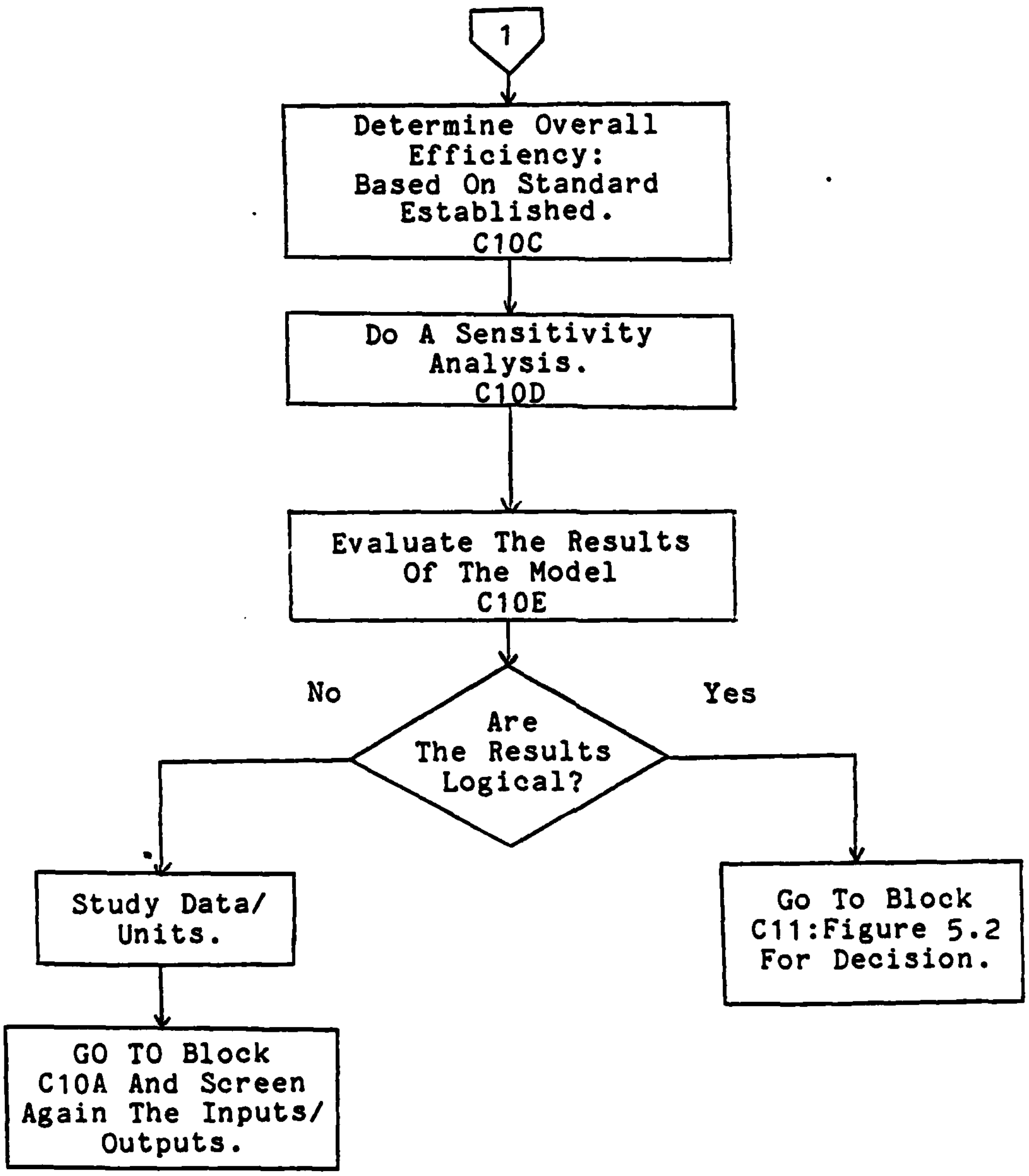

Figure 6.3. Suggested Procedure for Block C10 of Figure 5.2 (Continued)

variables and the second would be to study the data to identify relationships between variables.

1. Choose Inputs/Outputs (C10A1). All the inputs and outputs should be considered. Anthony and Young (13:478) say:

> . . . valid criticisms can be made about almost every output measure. . . [but, generally it is better] to recognize that some output data, however crude, is of more use to management than no data at all.

Block C10 of Figure 5.2 suggests some of the variables to consider. Once the manager determines the relevant variables, he then needs to determine which are quantifiable and which are not. Quantifying variables that do not lend themselves to quantification, can result in a distorted perspective. The National Research Council points out (51:33):

> . . . productivity statistics are not helpful and may be harmful if . . . there is no clear measure of output and . . . there is no well understood production "technology," that is, no efficacious procedures for reliably converting inputs into outputs.

Some techniques, such as SMART (57), can serve as these "efficacious procedures" mentioned above.[4] Finding accurate and reliable measures of inputs/outputs certainly is a challenge. The data determined not to be quantifiable

should be considered by the decision maker (Figure 5.2:C11) in addition to the output of the prioritization block (Figure 5.2:C10).

DEA assumes the measures chosen are accurate and determines efficiencies based on data in the data base. In using DEA one should choose input and output measures so an increase in an input measure of an efficient unit should be expected to cause an increase in one or more outputs. Without this positive relation between inputs and outputs, the efficiency ratio of outputs over inputs would be meaningless. Table 6.1 shows the inputs and outputs chosen for a sample run.

One may note from the outputs and inputs chosen that reciprocals had to be used to ensure that as inputs increased, so did outputs. For example, as government risk increases, the rating for government risk decreases. This set sets up the desired positive relation between the measure of cost to the government (input) and the measure of risk to the government (output). Higher costs should reduce risks and increase the RISK variable. In a similar manner, the inverse of the time to implement a Tech Mod program (1/duration in months) and the government payback (1/government payback period in years) were used. A thorough study of the data should be done to ensure the best measures are being used and the data has the proper relationships. One need not be concerned with the scale

TABLE 6.1

Inputs/Outputs for Sample Runs

Variables	Description	Source
SAV--U1 (Output)	Savings-all monetary savings, direct and indirect; the appropriate adjustment should be made for inflation, etc.	These figures were taken from cost benefit analyses (CBA) performed by or for the Air Force.
KINV--U2 (Output)	Contractor Investment-the amount of dollars the contractor will invest in modernization (not capital equipment) as a result of the Tech Mod program.	Proposal.
RISK--U3 (Output)	*Government* Risk-risk to the government of doing the proposal; rated 1 to 5, from highest to lowest risk.	Technical assessment currently being done by AFWAL (numbers are assigned).
TRANS--U4 (Output)	Transferability-the extent to which enabling technologies are produced (i.e., how generic or transferable the effort is).	AFWAL function (numbers are assigned).
SOA--U5 (Output)	State of the Art-the extent that the state of the art in that technology is advanced.	AFWAL function (numbers are assigned).
DUR--U6 (Output)	Duration-the time to implement the Tech Mod *program;* an inverse relation was required to obtain a positive relation between inputs and outputs (i.e., 1 / DUR).	Proposal.

TABLE 6.1

Inputs/Outputs for Sample Runs (Continued)

Variables	Description	Source
IRR--U7 (Output)	Government Internal Rate of Return-dollar summary of government benefits to cost, discounted for the time value of money.	Air Force Discounted Cash Flow Model.
PB--U8 (Output)	Government Payback-period required to recoup the dollars spent. This figure takes into account the time value of money. The inverse of payback (i.e., 1 / PB) was used to obtain a positive relation between inputs and outputs.	Air Force Discounted Cash Flow Model.
COST--V1 (Input)	Cost to the government in dollars. This figure should include all cost, direct and indirect. Often this is not the case, and the model can handle whatever criteria the decision maker would have used.	Air Force calculations based mainly on the proposal.

(eg., years versus months) because DEA ratings are invariant to scale.

2. Study Data (C10A2). Since the model will only perform as well as the data loaded into it, it is important for the decision maker to be familiar with his data. One method the researchers used to become familiar with the contracting data was to run Pearson correlations using the Statistical Package for Social Scientists (SPSS) which is resident on the AFIT computer system. The results shown in Table 6.2 indicated a positive relation between the input and four of the outputs. It further indicated that some variables such as IRR and payback (PB) measured the same thing, which tends to indicate either IRR or PB could be dropped from the model and the results would not change significantly. One should use such information to become familiar with the data, but caution must be exercised in drawing causal relations (49:420-421).

Establish a Standard (C10B). One of the largest problems with Tech Mod is the uniqueness of each program. As with most not-for-profit operations, there is not a single standard (such as profit) against which to evaluate programs. The purpose of this block (C10B) is to establish such a standard. To do so, one must decide what mix of inputs and outputs are desired. The process of determining this mix should include: first, constraining the mix of inputs and outputs to reflect any preferences known a priori

TABLE 6.2

Pearson Correlations

	U1	U2	U3	U4	U5	U6	U7	U8	V1
U1	1.0								
U2	.9453 .001	1.0							
U3	-.2790 .247	-.1936 .427	1.0						
U4	-.0202 .934	-.0533 .828	-.0161 .948	1.0					
U5	.0406 .869	-.0184 .940	-.3698 .199	.3191 .183	1.0				
U6	.1494 .542	.0956 .697	.4557 .050	-.0416 .866	-.0053 .983	1.0			
U7	.4739 .040	.3972 .092	.1603 .512	-.2850 .237	-.3304 .167	.2844 .238	1.0		
U8	.4011 .089	.3178 .185	-.0421 .864	-.2573 .288	-.3645 .125	.0776 .752	.9433 .001	1.0	
V1	.6689 .002	.7114 .001	-.2227 .360	-.0253 .918	-.1375 .575	-.0688 .780	.2127 .382	.1997 .412	1.0

Sample Size For All = 19

Format Of Entries:
First Entry: PEARSON CORRELATION COEFFICIENTS
Second Entry: SIGNIFICANCE

(C10B3); second, determining the technical efficiency (C10B4) to give the decision maker some alternative preferences (C10B5); third, selecting the mix of variables preferred; and finally, if the decision maker does not like any of the alternatives, provide a computer-generated standard (C10B6).

1. Constrain the Relative Value of Inputs and Outputs (C10B3). If the decision maker knows how to specify the relative value of inputs and outputs, he might be able to drive the solution in that direction with added constraints.[5] For example, if the rule of thumb (as exists for the B-1B Tech Mod program) is that the value of savings must be at least four times greater than cost, then just add the following constraint:

(U1) * SAV .GE. 4 * (V1) * COST .GE. 0. (6.5)

where U1 and V1 are multipliers calculated by the computer, and SAV and COST are measured values from the data loaded. (NOTE: ".GE." means greater than or equal to).

Other preferences could also be added. If, for instance, the decision maker knows that early in a project's life savings (SAV) is most important with quick implementation (DUR) next followed by risk to the government (RISK), then the following constraint should be added:

(U1) * SAV .GE. (U6) * DUR .GE. (U3) * RISK .GE. 0. (6.6)

In addition, if these are the only criteria the decision maker wants to use he can drop the other variables from the equation. It would be good practice, however, to run the model with more variables to help the decision maker better understand how model results change as a result of using the limited set of variables. After the run with more variables, some may be dropped to obtain a better defined comparison as discussed later in the chapter.

2. <u>Determine Technical Efficiency (C10B4).</u> All studies the researchers reviewed used the technical efficiency (DEA or CFA) to determine a unit's efficiency. In prioritization, the DEA technical efficiency ratings can be used to represent the relative worth of units only if the ratings were obtained by comparing the units to the same frontier facet. In other words, any units whose efficiencies are measured relative to the same frontier facet can be compared to one another based on their efficiency rating. Units which are rated relative to different frontier facets cannot be compared. This section will explore techniques to better define a facet and to compare units within different facets. To promote better understanding of these ideas, summaries from sample computer runs will be presented.

The first sample run included one input and eight outputs (see Table 6.3). The contracts labelled 3, 5, 9, 15, and 17 defined the frontier, i.e., they each received an

TABLE 6.3

Summary of DEA/CFA Output Using 8 Outputs/1 Input

DEA OUTPUT(SUMMARY)				CFA OUTPUT(SUMMARY)			
UNIT	EFF.	RELATIVE TO UNITS (FACET)	USING OUTPUTS EFF.	CHANGE IN	LOWER EFF. BOUND	UNIT BROUGHT INTO SOL'N	NEW OUTPUT VARIABLES
1	.858	3,5,17	1,2,3	0	.858		
2	.170	9,17	2,4	.016	.154	15	1,2,6
3	1.0	3	1,2,7	0	1.0		
4	.234	3,9,15,17	1,2,3,8	0	.234		
5	1.0	5	1,2,7	0	1.0		
6	.505	9,15	1,6	0	.505		
7	.363	3,15	1,8	.113	.250	17	1,2,4,5
8	.086	15	3	0	.086		
9	1.0	9	1,2,3,7	0	1.0		
10	.185	3,5,17	1,2,7	0	.185		
11	.316	15	3	0	.316		
12	.326	5,17	2,4	.006	.320	3	1,2,6
13	.122	15	6	0	.122		
14	.370	15,17	2,3,5	.050	.556	3	1.2.7
15	1.0	15	7	0	1.0		
16	.606	15,17	2,3,5	.050	.556	3	1,2,7
17	1.0	17	2,7	0	1.0		
18	.398	3,15	1,7	.15	.248	9	1,5,6
19	.816	3,9,15,17	1,2,3,5	0	.816		
% OUTPUT USED = 45/152 = .30				% OUTPUT USED = 51/152 = .34			
EFFICIENT UNITS ARE: 3,5,9,15,17							

efficiency rating of 1.0 (Column 1). All other contracts were rated against a subset of these five efficient contracts (Column 2). Column 3 shows which outputs were used as criteria in determining each unit's efficiency rating. For example, unit 3 was the most efficient unit based on the outputs (i.e., criteria) of savings (output 1), contractor investment (output 2), and government IRR (output 7).[6] DEA established the upper bound efficiency ratings for all contracts (units) based on the observed data.

The DEA technical efficiency reflects the maximum rating a unit can achieve. Because DEA assigns values to outputs in order to achieve the highest possible efficiency rating, the worst outputs of an efficient unit are frequently ignored, i.e., zero values are assigned to these low outputs. If no outputs were ignored then one would have greater confidence that the technical efficiency ratings were accurate (based on the data entered). Unfortunately, some of the outputs were ignored in the first run. That is, no rated unit is "fully enveloped" by enough efficient units so that all outputs are taken into account. Full envelopment of a unit occurs when the number of efficient units in the facet equals the sum of the inputs (s) and outputs (m), less one (s + m - 1). Since there are only five efficient units and a total of nine inputs and outputs, full envelopment is not possible. Without full envelopment of all inefficient units relative to the same facet, there is no uniform standard against which units can be compared.

3. Selecting a Standard. Without a "uniform standard" for comparing units, a decision maker may not wish to choose any of the facets or mixes of variables obtained from the DEA run. If not, there are at least two more approaches the DSS could pursue for the decision maker. The first would be an attempt to increase envelopment, and the second would be to artificially create a uniform standard.

3a. Increasing Envelopment. Three methods were considered to help increase envelopment: employ Constrained Facet Analysis (CFA), screen the variables, and screen the units (contracts).

The CFA method developed by Clark generates a nearby facet (25:93-122). This method will artificially bring more variables into the solution by extending the "frontier" in areas where there are no observations. Figure 6.4 shows how unit C (an outlier) is rated relative to facet AB, instead of just relative to unit B as in DEA.

The researchers ran the data (1 input and 8 outputs) using CFA. For the data set, CFA did not bring enough variables into the solution (Table 6.3, New Output Variables) to define any complete facets. In only 4 out of 19 cases did the number of variables defining the "incomplete" facets increase. The "percent outputs used" increased from 30% to 34%, indicating only slightly better facet definition.[7]

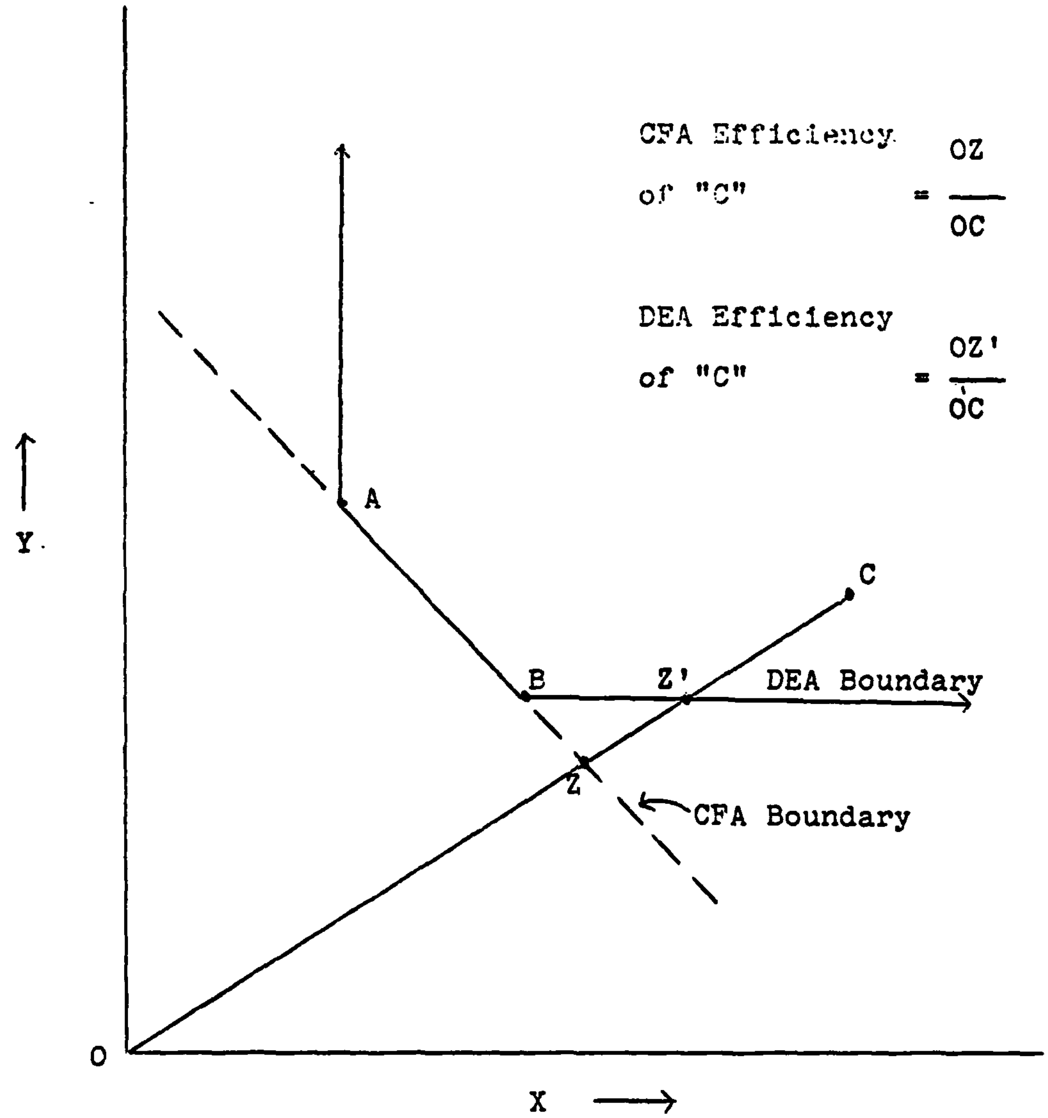

Figure 6.4. CFA Illustration

The next step was to reduce the number of variables thereby reducing the complexity of forming a complete facet. Two methods were used. First, the number of variables was reduced by eliminating all the variables that were considered to be mostly subjective. Secondly, the number of variables was reduced by eliminating an output if it appeared to measure the same thing as another output.

The variables remaining after removing the subjective ones were: savings (U1), contractor investment(U2), duration to implement (U6), IRR (U7), payback (U8), and cost (V1). The new run (see Table 6.4) showed the percent output used increased from 30% (original DEA run) to 45%.

Data was further reduced based on the Pearson correlations (see Table 6.2). IRR (U7) and payback (U8) correlation (.9433) showed significance to .999 indicating the two variables measured the same thing. Though no causal relation can be drawn solely on this correlation, logically, one would expect as the rate of return increases payback period would decrease. Since the inverse of payback was used as a measure of payback to obtain a positive input/output relation, IRR and payback measures are directly related--consequently IRR was dropped. As expected, the percent outputs used increased (from 45% to 50%), with very little change in the units' efficiency ratings. The maximum change in efficiency ratings was .008 (see Table 6.4 and Table 6.5).

TABLE 6.4

Summary of DEA Output Using Outputs 1, 2, 6, 7, & 8

UNIT	EFF	RELATIVE TO UNITS (FACETS)	USING OUTPUTS
1	.858	3,5,17	1,2,6
2	.164	5,17	2,6
3	1.0	3	1,2,7
4	.234	3,15,17	1,2,8
5	1.0	5	1,2,7
6	.505	9,15	1,6
7	.363	3,15	1,8
8	.061	15	7
9	1.0	9	1,2,6,7
10	.185	3,5,17	1,2,7
11	.225	9,15	1,6
12	.326	5,17	2,8
13	.122	15	6
14	.370	15,17	2,8
15	1.0	15	7
16	.578	15,17	2,6
17	1.0	17	2,7
18	.398	3,15	1,7
19	.766	3,15,17	1,2,8
% OUTPUT USED = 43/95 = .45			

TABLE 6.5

Summary of DEA Output Using Outputs 1, 2, 6, & 8

UNIT	EFF	RELATIVE TO UNITS (FACETS)	USING OUTPUTS
1	.854	3,5,17	1,2,6
2	.164	5,17	2,6
3	1.0	3	1,2
4	.234	3,15,17	1,2,8
5	1.0	3	1,2
6	.505	9,15	1,6
7	.363	3,15	1,8
8	.053	15	8
9	1.0	9	1,6
10	.185	3,5,17	1,2,8
11	.225	9,15	1,6
12	.326	5,17	2,8
13	.122	15	6
14	.364	5,17	2,8
15	1.0	15	8
16	.578	15,17	2,6
17	1.0	17	2,6
18	.396	3,15	1,8
19	.766	3,15,17	1,2,8
% OUTPUT USED = 38/76 = .50			

The third method employed to help develop a complete facet was to screen units. Removal of a "dominant" unit may also facilitate obtaining a complete facet (23). In Figure 6.5, removal of unit A would reveal a proper facet (BC) against which D would be rated. Since unit 15 appeared in many of the facets of the units rated (over half, see Table 6.3), the unit was removed in an attempt to reveal additional facets. When removed, more variables were brought into the solution; however, no complete facets were formed.

Had a complete facet been found or developed, then all units rated relative to that facet could have been prioritized by their efficiencies. However, that would not completely solve the decision maker's problem because it would not compare units of different facets. One technique that can be used to compare all units is to establish an artificial standard.

3b. Artificial Standard. The artificial standard the researchers suggest is derived from the "price efficiency" of some unit as suggested by Farrell (32:264). If the chosen unit was rated relative to a complete facet it would be a more complete measure of efficiency based on consideration of all the variables. In essence, the proper facet provides various efficient mixes of inputs and outputs which other units are rated against. If one knew the appropriate weights for the inputs and outputs relative

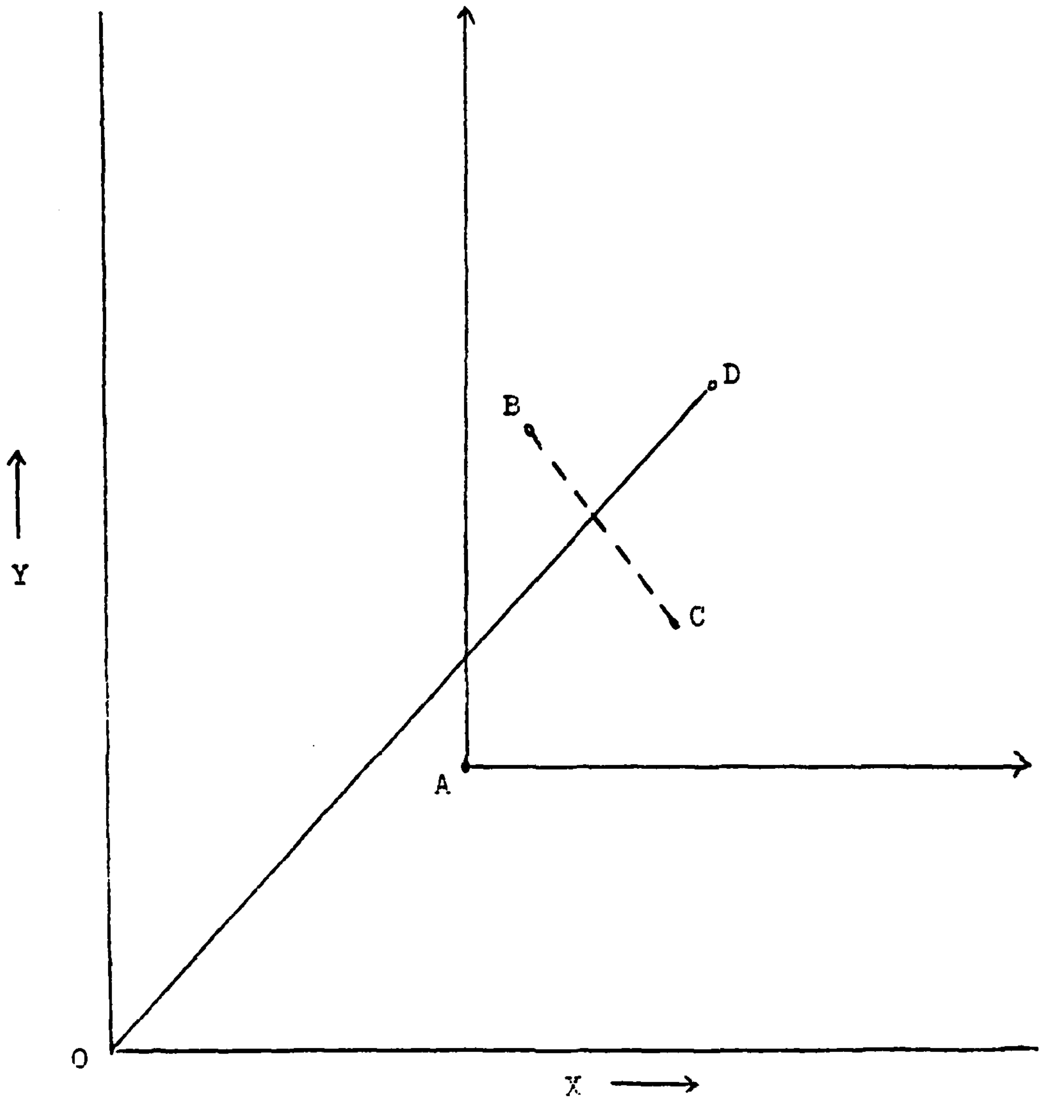

Figure 6.5. Unit "A" Dominates Other Units

priorities could be calculated.[8] This is not as difficult as it sounds using the output from DEA (C10B4). If a decision maker can identify a contract which has the approximate mix of inputs and outputs then the problem is solved. One can obtain from DEA the multiplier values assigned to the inputs and outputs of the units being evaluated. Clark (24) showed that these multiplier values are related to the slope of the frontier in the facet of the unit being evaluated. If the decision maker determines that these multiplier values are appropriate for all units, then all that needs to be done is to force every unit to have those same multiplier values. Equality constraints could be added to the DEA model to fix the values of the multipliers at the appropriate amount. However, since the software for the DEA model was inaccessible, a simple Fortran program was written to do the same thing (see Appendix). The Fortran program calculated the new overall efficiencies (see Table 6.6). The designer of the DSS should test the method of adding an additional constraint to DEA to ensure that it works and then determine which of the two methods is most efficient. The result to the decision maker should be the same, a rank ordering of programs relative to one efficient combination of inputs and outputs. The program as written compared each unit relative to all other units (see Table 6.6).

TABLE 6.6

Overall Efficiencies Using
Outputs 1, 2, 6, & 8

FACET USED BY UNIT:	STANDARD FOR COMPARISON: 1	2	3	...	19	AVG EFF.	DEA RANK	OVERALL RANK
UNITS THAT DEFINE FACET:	3,5,17	5,17	3	...	3,15,17			
ASSOCIATED OUTPUTS:	1,2,6	1,2	1,	...	1,2,8			
UNIT								
1	.854	.839	.842	...	.831	.626	6	6
2	.162	.164	.159	...	.156	.108	17	16
3	1.0	.957	1.0	...	1.0	.800	1	3
4	.210	.205	.203	...	.234	.188	14	14
5	1.0	1.0	1.0	...	.977	.670	1	5
6	.175	.158	.115	...	.195	.271	9	10
7	.252	.237	.242	...	.278	.248	12	12
8	.030	.028	.024	...	.039	.040	19	18
9	.957	.924	.885	...	.975	.869	1	2
10	.183	.177	.184	...	.184	.138	16	15
11	.022	.006	.009	...	.009	.064	15	17
12	.320	.324	.316	...	.317	.216	13	13
13	.015	.012	.001	...	.001	.027	18	19
14	.313	.284	.362	...	.362	.316	11	9
15	.857	.742	1.0	...	1.0	.938	1	1
16	.548	.546	.508	...	.573	.465	8	8
17	1.0	1.0	.953	...	1.0	.760	1	4
18	.220	.213	.206	...	.300	.261	10	11
19	.736	.730	.706	...	.766	.591	7	7

The decision maker may then compare contract 1 relative to contract 2 using the criteria (facet) for contract 1 or the criteria for contract 2. If contract 1 had a higher efficiency rating in both instances, then contract 1 would be the logical choice over contract 2. One could further check the ranks of contracts 1 and 2 relative to the criteria used by each of the other contracts. If contract 1 always had a higher efficiency rating than 2, one could be fairly certain that 1 was better than 2 based on the data entered.[9]

4. Computer Generated Standard (C10B6). The decision maker might also consider an average of the efficiency ratings for each contract relative to each of the other contracts (see Table 6.6, Column labelled AVG EFF).[10]

Overall Efficiency (C10C). The decision maker's choices will result in the establishment of a common basis of comparison and hence an overall rating for each unit (C10C). Since the decision maker may not be absolutely certain that the standard he chose is the correct one, he might want to consider several standards. Furthermore, the decision maker might want to know how sensitive each of the standards are to changes in the variables.

Sensitivity Analysis (C10D). The sensitivity of the program could be analyzed from two ways. First, analyzing the range of each of the variables over which the current solution is optimal. Second, the decision maker can ask

"what if" questions to help obtain more than one perspective on the contracts. Linear programming packages with sensitivity analysis capabilities are readily available (12:171). These analyses could tell a decision maker the range over which any individual variable could change and still provide an optimal solution. A decision maker may want an analysis run on each variable or he may want to focus attention on those with the most uncertainty.

The decision maker also has the option of asking many "what if" questions. Some of these questions may include: "What if inputs and outputs are added or subtracted from the variable list?" and "How will that affect the solution?"; "What if contracts 1,2, and 3 are removed from the list of candidates?"; and so on. The "what if" questions along with other forms of sensitivity analysis should be nested in a user friendly program.

Evaluating the Results (C10E). Though the model is being evaluated throughout the procedure, it is worth putting in a formal feedback loop to correct any deficiencies in the model. This model, the data that "feeds" it, and the DSS it is nested in all should be evaluated and improved upon in an iterative manner. Periodically evaluating the model will help ensure the model gives the decision maker the best information for his decision (C11).

Summary and Conclusions

This chapter has presented a sample expansion of one of the blocks of the normative model--Block C10. The expansion is both iterative and modular. The prioritization method is meant to be a tool to aid the decision maker in his decision. The answer derived from the computer may not be the best answer, depending on factors such as the inputs and outputs programmed in the model and the accuracy of those inputs and outputs.

There is an implicit assumption that the prioritization program will be nested in an understandable user-friendly program. With the emphasis on understandable, Chapter 6 explains how to interpret the results of this prioritization technique and no effort is made to concentrate on the details of the procedure. More detail was given on the overall efficiency determination because it is an extension of previous research. However, enough information (Appendix and references) was given so a designer could implement such a system.

This is the first attempt the researchers are aware that DEA and CFA have been applied as a prioritization technique. Though the application as suggested is for the Tech Mod decision process, there are potentially many more applications, especially in the contracting area. Prioritization using this technique is ripe for future research.

Footnotes

1. The terms contracts, programs, and units (Decision Making Units--DMUs) can be used interchangeably throughout this chapter since the only difference for prioritization would be the inputs and outputs used.

2. The DEA portion of the model was run on a personal mini-computer of another AFIT student named John Fraser (34).

3. An advancing frontier implies that at any point in time a unit is as efficient as it can be, but as time goes by and technology improves even the most efficient units can improve.

4. SMART is a technique developed to rank subjective areas. Quantifying subjective areas is an important consideration but will not be covered in this thesis

5. Adding an additional constraint was not actually tried by the researchers and has, therefore, not been proven to work. Intuitively, the researchers feel this method should work, but the proof would require running of the actual model and a mathematical proof. In the mathematical proof, one would have to show either that both the primal and dual have feasible solutions, or that the dual or the primal has a solution that is both feasible and bounded (23).

6. The computer run also supplied other information such as the mix of inputs and outputs (multipliers).

7. Since the researchers needed a standard measure of how closely a unit approximated a proper facet, "percentage outputs used" was developed (total outputs divided by total outputs possible).

8. The calculation used in the Fortran program (Appendix) to calculate these relative efficiencies was:

$$\text{Efficiency} = \sum u_i y_i \ / \ \sum v_j x_j$$

where u_i is the weight of the i^{th} output

v_j is the weight of the j^{th} input

y_i is the value of the i^{th} output of m total outputs

x_j is the value of the j^{th} input of s total inputs.

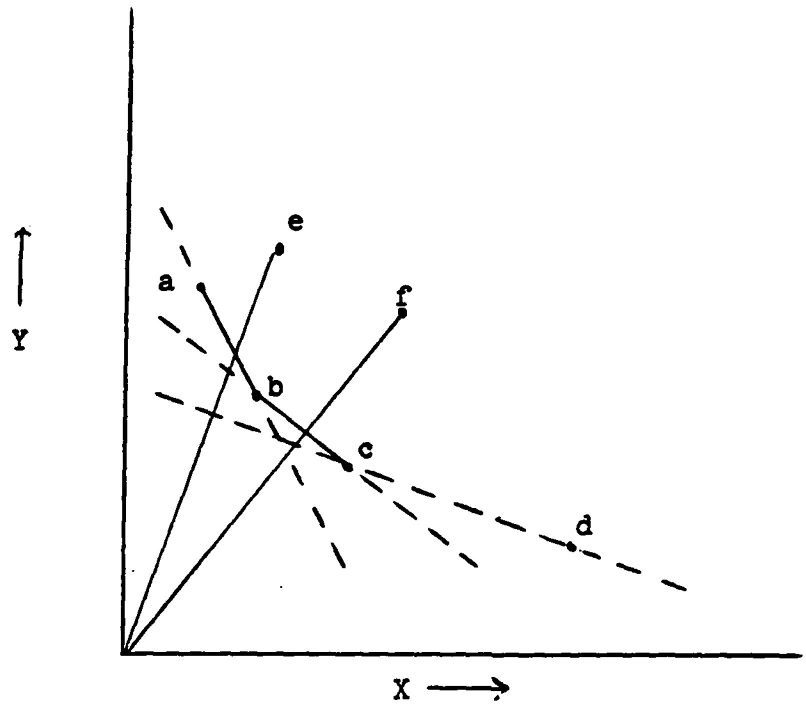

Figure 6.6. Unit Price Efficiency Comparison

9. If no units are measured against a facet, then that facet will be ignored with the above technique. In Figure 6.6 facet "ab" will be discovered when "e" is evaluated and "bc" will be discovered when "f" is evaluated; however, facet "cd" will not be discovered since there are no inefficient units rated against "cd". Further research may indicate how to discover these hidden facets. One method would be to introduce an artificial inefficient unit which is a linear combination of units "c" and "d".

10. The method would not necessarily include all frontier facets for the reason described in footnote 9. Furthermore, some facets may receive extra weighting if more than one unit is rated relative to it. This may be desirable if that facet is considered more important (maybe due to more competition for that mix of inputs and outputs). If the weighting is not desirable one could eliminate by identifying units with the same input and output mix and eliminating them.

VII. Findings, Conclusions, and Recommendations

Chapter Overview

This chapter presents the findings, conclusions, and recommendations of this research effort. The chapter is arranged in three sections: findings and conclusions based on the four research questions this thesis addressed; recommendations for future research; and closing comments.

Findings and Conclusions

Research Question 1

WHY IS THERE A NEED FOR THE TECHNOLOGY MODERNIZATION PROGRAM?

Findings. Effectiveness in a contingency situation typically requires a deployment of forces and other resources. To the extent that operations can be sustained (i.e., effective for a specified time period) depends on such factors as the resources deployed with the forces, the pre-positioned resources, the pre-stocked resources, and the lead time required to produce resources. Lead time is often measured by the ability of industry to surge and/or increase capacity.

To determine what is required, an analysis of the contingency requirements as well as peacetime requirements is necessary. At first, one may think effective contingency and efficient peacetime operation presents conflicting goals. However, further study should reveal that the preparation for war should be a required output of peacetime operations.

Effectiveness for contingencies can be maintained more efficiently if industry is more efficient. Excess peacetime capacity will still be required to meet the contingency requirements, but this excess capacity may be on a smaller, more productive plant. Likewise, if the modernization improves lead times, pre-stocked assets could be reduced. Furthermore, if failure rates and/or repair times can be reduced, less spares will be required.

Reduced cost, reduced lead times and increased benefits are some of the major benefits associated with modernization. One can conclude that modernization is in support of national objectives. Furthermore, studies have shown modernization has not taken place in the U.S. at the rate that it should. The reasons for lack of modernization came down to the bottom line--the current Tech Mod environment does not offer enough incentive for defense industry to invest and often there is a disincentive.

Research Question 2

WHAT DECISION PROCESS HAS BEEN UTILIZED TO SELECT PREVIOUS TECH MOD PROGRAMS AND PROJECTS?

Findings. The Tech Mod decision process differs between the three programs examined; however, there are common elements in each. Chapter 4 outlines these three processes. Often, decisions are driven by political considerations. Furthermore, even though the programs are designed for long term productivity increases, there is always the problem of justifying the program to the resource providers in the short term.

Conclusions. The decision processes outlined in Chapter 4 have a common core of logic throughout. This generic logic is presented in the Normative Model in Chapter 5.

Research Question 3

HOW WOULD A DSS BE STRUCTURED TO ASSIST TECH MOD MANAGEMENT, INCLUDING PROGRAM OR PROJECT SELECTION?

Findings. Investigation revealed massive amounts of data goes into making a Tech Mod decision. Furthermore, much data is neglected due to time and knowledge constraints. In spite of time and manpower limitations, each Tech Mod manager interviewed was doing a good job. However, the limitations forced fewer programs and less factors to be considered in the selection process. Some areas of the decision process were already being

computerized, such as some financial calculations; however, there was no program that integrated the desired information.

Conclusions. A DSS can be very beneficial to a decision maker in the Tech Mod process. The DSS would allow one to consider more information in less time. The implications being better decisions on more programs with the same or less manpower.

Research Question 4

WHAT TECHNIQUE OR METHOD CAN BE USED TO PRIORITIZE TECH MOD PROPOSALS AND SIMULTANEOUSLY TAKE INTO ACCOUNT MULTIPLE CRITERIA?

Findings. Research presented in Chapter 6 demonstrated how multiple input/output situations can be rank-ordered using allocation efficiencies developed from a linear program in concert with a decision maker. The prioritization obtained can be viewed from several perspectives by having the computer calculate the efficiencies based on different variables.

Conclusions. The system developed by the researchers has potential in profit and non-profit organizations alike.

Areas for Future Research

The recommendations for future research can be broken into five categories.

I. Expand/Validate the Predesign Phase (Figure 5.2)

There are two specific recommendations for future research under this category:

1. Review and update the predesign phase presented in this thesis. Since the Tech Mod decision process had not been structured for a DSS before, there were many areas that were briefly covered. One can build on, or modify, the DSS developed herein. Using this thesis as a baseline, more case studies could be done of other Tech Mod decision processes. Some of the other decision processes that would be of interest would be the Propulsion SPO and a few Army and Navy "Tech Mod" programs. This larger background could be used to confirm or modify the DSS.

2. Investigate competing Tech Mods as is done for source selection. Often, in source selections, there are much fewer potential sources than is the case with Tech Mods. The assumption is if the Tech Mod dollars are limited then competition will allow the government to receive the most for what is spent. In doing this study, one could draw parallels between the Tech Mod decision process and source selections. Possibly a panel of diversified experts (as in source selection) can come up with a better way to understand or measure subjective areas, a better ranking of programs, or a better way of constructing the "business deal."

II. Extend the Predesign Phase Through the Next Two Steps

There is room for several studies in this area that can be summarized in the one recommendation below:

1. This thesis brought one through the "predesign" phase of DSS development. A logical extension would be to continue through what Keen and Morton (42) call the design and implementation phases. In doing so, one would look at compatible hardware and

oftware, and determine the compatability with current systems. One would also look at the formats of reports that could be most useful to the decision maker.

III. Expand/Validate the Prioritization Block (Figure 5.2: C10)

There are five specific recommendations for future research under this category:

1. Investigate the validity of the prioritization scheme developed in this thesis. One could select a Tech Mod program like the B-1B and prioritize the projects based on several criteria. Since there were over 700 projects initially, the program could be extremely useful. Once the computer program was run, the output could be compared to the actual success of the projects. One may then compare the actual input/output mix of the projects selected are relative to what they were thought to be. If the mix is significantly different, maybe there are extraneous factors that were included in the decision which were not formally mentioned. Any such factors identified would be useful even if they could not be quantified. A different input/output mix than expected may also occur because the "best" programs were not chosen due to lack of information at the time or political considerations.

2. A second method of validating the prioritization scheme would be to evaluate the projects of several Tech Mod programs using the prioritization scheme developed herein. Determine how many current projects would be eliminated in favor of other more beneficial projects in programs not chosen. As part of the Cost Benefit Analysis, one should consider how eliminating projects from programs would affect contractor commitment.

3. Expand the prioritization technique developed in this thesis. This thesis did not show that a manager could add additional

constraints to the system. Footnote 5 in Chapter 6 details how this proof would be developed. Further research may also prove a more effective way of establishing a standard to rate other units against. This may come from identifying the "undiscovered facets" explained in footnote 9 of Chapter 6. The appropriate weighting of the facets, if any, should also be considered.

4. Many of the costs and benefits require subjective estimates by the decision maker. The accuracy of these estimates can sometimes be improved by some quantification techniques that helps guide one or preferably several through a structured process. SMART (57) and Delphi (47:497-500) are two such techniques. Further research on the most applicable technique may help the decision maker structure his decision process to the point where the numbers become reliable. Two large potential benefits are the structuring of the subjective decision process and the quantification of reliable measures that could be entered in a DSS.

5. Another aspect of the prioritization technique worth investigating is a method of counter-bidding proposals to contractors. Logically, if programs are rated on an efficiency ratio of benefits divided by costs, then one could increase the efficiency of a non-efficient unit by reducing cost. This cost reduction could be reflected in terms of a counter bid to a firm. If those firms wanted contracts they would have to reduce the cost to the government. The more contractors reduced government cost to enter the Tech Mod market, the closer the "piecewise frontier" would approach the "theoretical frontier" and the more competitive the Tech Mod marketplace would become.

IV. Expand the Cost Benefit Analysis Block (Figure 5.2: C6)

There are three specific recommendations for further research in this category:

1. Analyze how Cost Benefit Analyses (CBA) are being done and if there is some standard means that will help the decision process. Many CBA use direct labor as a surrogate for performance. In a presentation given by Price Waterhouse to the Air Force it was pointed out that one company had 60% of their standards based on direct labor, yet only 3% of the cost could be attributed to labor and consequently overhead linked to direct labor can be disproportionate. To the extent the cost accounting standards can be improved, one can better predict how different factors will affect the cost-benefit forecast.

2. The extent that a decision maker can rely on the output of a CBA depends on the certainty of the inputs/outputs. Since the CBA currently is the major factor in program selection, it is worth examining how accurately these measures are. A procedure for the research may be as follows:

   STEP 1--Look at a typical CBA for a small program or two.
   STEP 2--Examine decision process and determine its structure.
   STEP 3--Take each or at least some of the factors and vary them to see how sensitive the program is to their change. Candidate factors will include:
   - ---the number of end item buys
   - ---inflation
   - ---learning curves
   - ---program stretchout
   - ---does change = cost?

3. Another area that may prove fruitful for expanding the CBA block is to investigate any time dependencies in data used for forecasting cost. This study may use the following hypothesis: Time series analysis can be used to improve forecasting of the cost data for machines that are being considered for Tech Mod. If a better forecast can be obtained, there is less uncertainty for the contractor and the government and consequently it is easier to plan and make decisions. The trade-off is, of course, the cost of gathering the data. The methodology followed may be to examine a

period, say 1979 to 1980, and forecast another period, say 1981, using time series analysis and using the method currently in use. Then compare the results of both methods to the actual data to determine which is more accurate. General Dynamics indicated they could supply a tremendous amount of data on their Tech Mod program. Since at least 50 data points should be considered, an established program such as General Dynamics' is suggested.

V. Expand Other Blocks of Figure 5.2

This category contains the final area recommended for future research:

1. One of the blocks that would be useful to expand is block A7 (Establish Technical Indicators). One would need to review potential candidates for technical indicators then confirm they are valid indicators by some means such as statistics or surveys of experts in the field. Indicators such as patents (55), depreciation claims, age of equipment, and the like could possibly be formulated in a model to evaluate industry.

A Final Word

Tech Mod was created out of necessity to produce a weapon system, the F-16, in an efficient manner while complying with DoD policy prohibiting ownership of facilities and equipment. The evolution of Tech Mod since its inception has led to a program in which the government invests millions of dollars in return for tremendous quantitative and qualitative returns.

Since more effective decisions can result in great returns beginning to understand the factors involved in Tech Mod, this thesis has suggested a DSS as a way to handle the great amount of information that should be considered. The DSS flow developed herein can be considered a baseline decision makers can expand and modify to meet their needs. Computerization will allow the process to be expanded in many areas without overloading the user with the details.

A significant challenge for the future will be the refinement of the details involved in the Tech Mod process. As more data is assimilated, one should be able to better understand the Tech Mod factors. Study of the data should reveal the accuracy and help refine the quantitative and qualitative measures.

Appendix: Fortran Program That Rank Orders Programs by Allocation Efficiencies

```
      integer a,b
      real sav,Kinv,risK,trans,soa,dur,roi,pb,qual,cost
     1,u1,u2,u3,u4,u5,u6,u7,u8,u9,v1,avgeff(19)
      data sav,Kinv,risK,trans,soa,dur,roi,pb,qual,cost/10*0./
     1u1,u2,u3,u4,u5,u6,u7,u8,u9,v1/10*0./a/0/b/0/avgeff/19*0./
      open(unit=1,file = 'multi')
      open(unit=2,file = 'Kdata')
      open(unit=3,file = 'thesis')
      rewind 1
      rewind 2
      rewind 3
      do 20 j = 1,2
         a = 0
         b = b + 1
         read(1,*) u1,u2,u3,u4,u5,u6,u7,u8,u9,v1
         write(6,*) u1,u2,u3,u4,u5,u6,u7,u8,u9,v1
         rewind 2
         do 10 i = 1,19
            a = a + 1
            read(2,*) sav,Kinv,risK,trans,soa,dur,roi,pb,qual,cost
            write(6,*) sav,Kinv,risK,trans,soa,dur,roi,pb,qual,cost
            sav = sav/1000.
            Kinv= Kinv/100.
            dur = dur*100.
            pb  = pb*10
            cost= cost/100.
            eff= .0
            eff = (u1*sav + u2*Kinv + u3*risK + u4*trans +u5*soa
     1       +u6*dur +u7*roi +u8*pb +u9*qual)/(v1*cost)
            avgeff(a) = (avgeff(a) + eff)/real(b)
            write(3,*) 'CONTRACT',a,eff,'     RELATIVE TO CONTRACT:',
     1      b,'   AVG EFF SO FAR:',avgeff(a)
 10      continue
 20   continue
      end
```

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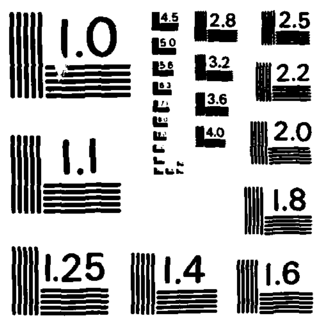

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Major Gregory F. Padula graduated from Louisiana Tech University with a B.S. in Electrical Engineering in 1973. By March of that year he was commissioned in the Air Force and began pilot training at Columbus AFB, Mississippi. In July 1973 his wife, Effie, gave birth to their first daughter, Amanda. After graduation from pilot training he was assigned to Sheppard AFB as an instructor pilot in T-37's. In October 1977 he arrived on station at McGuire AFB, New Jersey. In the five years spent at McGuire he flew as an Instructor Pilot in C141's, and held positions as a Command Post Duty Officer and as a Current Operations Airlift Director. In July 1982 the announcement of their second daughter, Dawn, was made.

In October 1982, Major Padula was assigned as Chief of the Integration Office, Aeronautical Programs, Acquisition Logistics Division, at Wright-Patterson AFB, Ohio. In June 1983, he entered the master's degree program in Graduate Logistics Management at AFIT. After graduation he will be assigned to the Air Force Coordinating Office for Logistics Research (AFCOLR) at Wright-Patterson AFB.

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Technology Modernization (Tech Mod) is a DoD effort to incentivize U.S. industry to modernize their facilities and procedures. For DoD personnel to effectively manage the Tech Mod programs, they must not only understand the Tech Mod processes, but also the factors that control and influence the process. This thesis examines the environment that Tech Mod operates in, studies three Tech Mod decision processes, develops a normative decision process that can serve as a basis for a decision support system (DSS), and finally, it demonstrates how the normative model developed can be used in a DSS. The study of the Tech Mod environment coupled with the Tech Mod case studies were used to develop the normative model. In exploring ways to expand one of the modules in the flow diagram, the researchers developed a prioritization technique using as a basis the linear programming technique called Data Envelopment Analysis. The method developed ranks multiple input/output contracts using technical and allocation efficiencies as a basis. The method further allows the decision maker to analyze the prioritization scheme from several perspectives, thus giving him a better understanding of the problem (inputs/outputs). The method may have generic application for profit and non-profit organizations alike. Further research in this area should prove fruitful.

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